W.E. Wood

WESTERN AUSTRALIAN INSTITUTION

OF

ENGINEERS.

PROCEEDINGS.

VOLUME 4.

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NOVEMBER, 1913.

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W. E. Wood

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PRESIDENTIAL ADDRESS.

(BY HUGH OLDHAM.)

In addressing the members of the Institute I wish to tender my thanks for the honor which they have seen fit to place upon me. It is my earnest hope that I may during the term of my presidency, in some measure justify their confidence.

The assumption of these responsibilities carries with it a sense of the increasing importance which the efficient continuation and development of this Institution possesses for the engineer of this State.

When the rules were drawn up by which the Institution is controlled, the founders in their wisdom made it possible to elect individuals to the position of honorary members. So far there has been only one election of this type, but this solitary application of the rule proved to be a signal success as to emphasise the feeling of loss we experience in recording the removal from this State of our honorary member Sir Gerald Strickland. The thoroughness and energy, which was a distinguishing mark in the character of this talented gentleman, in whichsoever of the many parts he was called upon to play, was not wanting in

his connection with this Institution, and our members have listened to his remarks, not merely with the perfunctory attention which is so often given to an official speech, but with the pleasure which is always accorded to the utterances of one who has the knowledge of men and things that is possessed by our esteemed ex-Governor. Although not trained in our profession, he was so widely read as to be able to enter into our discussions with the fullest appreciation, and in expressing the evident regret of the members of this Institution at his departure, I think I can safely suggest that the feeling is reciprocated, and that His Excellency has not severed his active connection with our body, without some thought of the pleasant and instructive evenings which we have passed together. The best wishes of this Institution are accorded to him in his new appointment.

There is another notable absentee from our midst—I am glad to say only temporarily. I refer to our first President, Mr. James Thompson. After an uninterrupted period of twelve years' work, the Engineer-in-Chief has been able to take a well-earned holiday, during which he proposes to make a tour of the world.

Quite recently, the movement, which has for a long time been taking shape, has suddenly culminated in the establishing of a University in Western Australia. The extremely businesslike and expeditious manner in which the Senate has dealt with this important matter cannot fail to appeal to the members of a profession in which actions, rather than words, are held in esteem. As the direct result of the consummation, and as a kind of first fruit from this garden of knowledge which has so suddenly sprung up around us, we have with us to-night as a newly elected member our very good friend Professor Whitfeld, who comes among us twice welcome, in the first place as a most valuable acquisition to our working ranks, and in the second place as an outward and visible sign that the good work has at last been accomplished, and that Western Australia in general, and its Institution of Engineers in particular, is now fully equipped in competition with the outside world.

Negotiations have been in course for some little time regarding the particular methods which are to be adopted in connection with the engineering course at the University. It is now certain that the sandwich system will be used. This particular system has been thoroughly discussed of late in the engineering world, and needs no lengthy description by me. It does not necessarily involve any notable departure from the usual arrangements so far as the instructional methods of the University are concerned. A novel feature, however, consists in the idea of a Board of Studies, including the Engineering faculty of the University and several of the leading State engineers, one of which

(I mention as being of special interest to members present) is to be chosen by this Institution. It is proposed that the University instruction shall cover the six winter months of each year, and that during the six summer months the students shall continue in a course of practical instruction to be arranged by the joint Board, as cadets in the State engineering service. As regards the beneficial effect of such a course upon the student, I presume that there can be no two opinions. The system will permit of his learning the application of his studies as he proceeds. It is assumed that he will be paid during the practical part of his training, which will assist him to support himself during the University course.

It may be argued that cadets working on this method will be of less value to a department than those who have hitherto served a continuous term in one branch of the service. I think that this disability must be admitted. Furthermore, during the winter months the service would be altogether without cadets under this system, and this may be urged as a further drawback. It should be remembered, however, that any of our cadet systems have, as their main object, the training of engineers, and it seems certain that the ultimate value to any department of a graduate trained on the proposed lines will far outweigh such disabilities as I have referred to. Again, this State has hitherto kept well in the lead with its admirable policy of free educaiton. Such a system as that under remark is only the latest enunciation of that policy which decrees that there shall be no bar to the acquisition of knowledge, except the lack of brains.

In the interests of this wise proposal, I would urge upon those members of this Institution who are entrusted with the control of the large engineering establishments of this State, to use their best endeavors to meet the University in its efforts to bring about the complete establishment of this system of teaching in alternative instalments, the theory and practice of our profession. Although the greater part of the engineering work in this State may be under the control of the Government, yet there are many large projects in private hands, and there is surely an opening in this direction for some of the students who are seeking practical knowledge. I am deeply convinced of the utility of the scheme, and intend to do my utmost, whilst in the capacity of President of this Institution, to assist towards the perfecting of these proposals.

Having now attained to such a satisfactory position as regards our facilities for the development of the profession, as we enter upon the new era, it is of interest to record where we engineers of Western Australia stand at the present day, in comparison with engineering advancement in other parts of Australia, where the opportunities, in the past, have been greater.

Familiarity with a subject tends to place it in the realm of the commonplace, and I think members might experience some surprise at the number of indications of advanced practice which exist, in connection with the works which comprise our everyday occupations in this State, were they to make an exhaustive search of the subject. This, of course, it is impossible for me to do to-night, and I do not propose by any means to treat in detail the various engineering enterprises with which we are already more or less familiar ; but rather to emphasise in each section some of those developments which indicate the state of advancement of our engineering knowledge.

Foremost in the category of our works are undoubtedly those which are connected with transport, embracing, as a main feature, our State railways. In the various branches of this system can be pointed out many interesting evidences of advanced thought and practice. With the rapid development of the agricultural areas of the State there has been a call for spur lines of an economic type and capable of rapid construction. A light line has been evolved which well fulfils both these requirements. Enquiries are now in course as to the possibility of further meeting the demand by the use of a mechanical track-laying device. The work has lately been taken up which is necessary to meet the large demand for sleepers. There is already a State sawmill in work at Dwellingup, which is designed on the most modern lines, and the programme includes the erection of several other mills, all of which are to be equipped with the latest type of American mill gear. These mills will operate to a great extent on the Karri forests, and it is proposed to instal Powellising plants in conjunction with each undertaking

In the section dealing with the railway management and control there are also many interesting points. For instance, as regards interlocking gear : all double lines are already equipped with the block system, while a very large mileage of important country lines is thoroughly equipped with the electric staff system. In connection with the patrol and inspection of the lines, a considerable use is made of the internal combustion driven type of machine. Both motors and motor-tricycles are used for this purpose.

There is a special development now on foot in the way of the adoption of specially large turn tables. Four of these are under design. They will be 80 feet in diameter, and will run on the latest approved type of ball bearings. A development which also indicates the type of practice exists in the use of spring frog crossings in connection with the permanent way. These are being largely adopted.

A further item of special interest is the excellent provision which has been made as regards sanitary conveniences at some of the larger country stations. In districts where there is no permanent town water supply (which might reasonably be looked upon as the precursor of up-to-date sanitary arrangements) there are nevertheless most complete conveniences. The platform arrangements, which are of latest type, are connected to a small septic tank with its accompanying filter, which delivers into a sump, the contents of which are emptied from time to time by means of a windmill. The filtrate is, in some cases, discharged at a considerable distance from the settlement.

It is of course known amongst the profession that the question of electrification of the railways in the metropolitan district is under consideration, in connection with the proposal to erect a large Government power-house, which it is expected will supply electric current for all purposes in the metropolitan area. This scheme opens a most comprehensive vista. The magnitude of the position will permit of a unit charge so low as to render the use of current possible for all industrial and domestic purposes.

In connection with the provision and upkeep of rolling stock, the State is extremely fortunate in the possession of a very large and recent-type workshop—in point of fact, the most up-to-date establishment of its kind in Australia. Despite the immense size of the original structure, it has been found necessary to duplicate, and a considerable amount of this work is already completed. The workshops are most completely equipped and the majority of the machines are run on the individual electric drive system.

Two of the many machines of special interest are the weighbridge and the testing machine, which are both fine examples of modern appliances, the former being quite unique in design. Attached to the workshops are general offices, drawing offices and laboratory, all on modern lines. A complete sanitary service with septic treatment is provided.

At these shops all the repairs to rolling stock are carried out, and a great deal of new work is constructed, including locomotives, rolling stock, points, and crossings, and other portions of the permanent way. As regards rolling stock recently imported, perhaps the most remarkable instance is that of the "Garrett" locomotive, several of which type have been recently put into commission. These are specially suited for hill climbing where there are sharp curves and where the road is light. Under such conditions they are capable of drawing a remarkable load.

Special attention has been directed to the provision of a maximum of comfort in connection with the design of corridor and dining-car stock. Despite the fact that the narrow gauge

of 3 ft. 6 in. obtains throughout the whole State, this type of car has been designed in such a way that the overall width of the car is the same as that of similar stock running on the London and North-Western Railway. There is naturally a considerable difference in speed necessitated by such an arrangement.

There are two other types of locomotive that have been recently introduced. In the first case, the "D" type, which is a 4-6-4, with a tractive force of 16,160 pounds, and which has been adopted in the suburban traffic in place of the older "N" type, which is a 4-4-4, tractive force 14,610 pounds. In this alteration, the Department has followed closely on the heels of the practice in the Eastern States. The change has been brought about in each case by the increasing claims of the suburban traffic. The other loco. is the "F" type, an engine rather uncommon at present in Australia. Two of these engines have been imported. The wheel arrangement is 4-8-0, and the novel feature consists in the provision of a Schmidt superheater. The steam temperature is raised to about 650° F. These engines are running between Midland Junction and Northam. Recent returns have been made available, which show the following average saving on the more ordinary types, viz., coal 35%, water 38%.

The producing capacity of the Midland Junction workshops is supplemented by large private shops, where various classes of stock are constructed. These shops, which are of comparatively recent erection, are furnished with all the latest improvements.

As a component part of our State transport, reference may be made to our harbor work and appliances. Fremantle Harbor stands out as an instance of modern engineering. This work was conceived and carried out under the actual personal supervision of that eminent engineer who has left so many monuments of his genius in our State, and who may so suitably be termed the progenitor of West Australian engineering. In the later equipment of the harbor, the original standard has been maintained. The existing installation of electric cranes was recently added to by the provision of three travelling cranes, and a further complement of four electric gantry cranes of the latest type is now on order. There is also a very complete and up-to-date system of electric travellers and loaders for dealing with the fast increasing wheat business. This plant represents the last word in the handling of bagged wheat. Indeed, it would appear that any further development in the matter of the wheat shipping problem would necessarily be in the direction of bulk handling.

Regarding other harbor works, the matter of the provision of reinforced concrete wharves is now receiving close consideration, while the use of protective pile coating of similar material has been in existence for some time.

Modern high power lightning flash apparatus has been installed in all the more recent lighthouses, together with incandescent kerosene burners, while on lesser lights the "Aga" unattended system, recently described in a paper read before this Institution, has been applied with much success.

The field of hydraulics provides some points of interest in this matter of modernity of ideas. The Goldfields Water Scheme is admittedly quite unique in many ways. The construction of its 360 miles of rising main, with a longitudinal joint, which was at the time of construction quite unproved, but which has fully justified its adoption, stands out as one of *the* hydraulic works of the world. There are eight lifts in this scheme, with full duplication of pumping plant throughout, the total dead lift being about 1,290 feet, capacity five million gallons per diem.

A somewhat remarkable local invention in the way of a power driven lead caulking machine was perfected upon this scheme. This machine was very ingenious and did very cheap and efficient work. Quite recently there has been additional work carried out in connection with the water treatment, necessitating the construction of several large summit tanks. These have been designed on the lines of the latest practice in reinforced concrete. The Helena Weir, though now somewhat dwarfed in comparison with the two recent immense works in New South Wales, was at the time of construction quite an ambitious work for a young State. I confidently quote this scheme as an example of the class of engineering of this State, and if I could give no other instance I should be quite satisfied to "stand pat" on this undertaking as irrefutable evidence of our engineering status.

Another large undertaking which is approaching completion is the Metropolitan Sewerage Scheme. The treatment process in connection with this work is on the biological system, and is by far the largest of its type in the Commonwealth. In this scheme reinforced concrete was first introduced into the State in a large way in both the treatment works and the main sewers. A distinct improvement on ordinary methods, which has since been adopted in the Eastern States, was the substitution of oval reinforced sewer pipe for the usual stoneware pipes from 21 inches down to 12 inches. In yet another instance has Western Australia set the lead. In the severage schemes in the Eastern States the boundary trap is universal. In Western Australia the practice has been adopted of omitting the boundary trap on all house connections where there is no inside water closet. This system is a radical departure from the old-fashioned methods. So far, its adoption has proved most beneficial from all points of view, and a most substantial saving in costs of ventilation and house connection has been made.

There is another section of engineering, which has its own Institute, and which for physical and geographical reasons is quite separate from us, but which at the same time plays such a prominent part in the development of the State as to demand at least a passing notice. I refer to mining engineering on the Goldfields. Even those of us who are least informed in this branch of engineering have many times in the last sixteen years had the conviction forced upon us by the sheer magnitude and prominence of the matter that there were many capable engineers engaged in this work. During the period mentioned the development has run through all the stages from the old-fashioned battery and quicksilver treatment to the amazingly economic methods which are at present in use. Probably the latest free gold treatment in the world is covered by the method of sliming combined with the "Castle" vacuum process of cyanide extraction, now in use at Kalgoorlie, while in the treatment of telluride and other refractory ores our goldfields practice is admittedly right in the lead.

Similarly, as regards mechanical engineering on the Goldfields, there are evidences of enterprise on all sides. Quite recently the suction gas plant has come into great favor, more especially the newer development, where the direct use of green wood in the furnace has been made possible, while there are innumerable instances of every one of the most modern types of prime mover at work in various parts of the fields. In fact, it is no exaggeration to say that this portion of our State teems with examples of modern practice. It is not in my province to do more than lightly touch upon this subject, but in passing I desire to do royal tribute to these talented brothers of ours who are so capably developing our vast mineral resources.

I have so far dealt with some of the large engineering departments of the Government and the larger industrial works. There are, however, many other developments, in both Government and private departments, where there is strong evidence of up-to-date management and practice.

An industry which, by reason of the isolated nature of the work, does not come prominently before the general engineering section of the community, but which is nevertheless a very considerable importance to the welfare of this State, is the saw-milling industry. Most of the mills are now right back in the centres of the various belts of first-class timber, and are a long way from the ordinary highways of traffic. It is, however, right to record that many of these mills are equipped with the most modern machinery and are handled on very up-to-date lines, while there are many clever instances of railway engineering to be seen on the timber roads connected with them. Taken al-

together, there is abundant evidenec of the fact that this great natural asset has been developed by men who are very wide awake to the advantage of modern method.

Time does not permit me to expand my subject further, otherwise I should have liked to have traversed our municipal work, and also the many other Government and industrial undertakings of which we are cognisant. I believe, however, that I have quoted instances which suffice to illustrate the high standing of our profession in this State.

I have a few words to say to the younger members and students of the Institution. They represent the section of our Society upon which the fullest benefit of the new order of things will fall. They can rightly claim that the University in part belongs to them. It is in truth their University, made to fit their requirements. Should the vision arise to any one of these of an established position with a cosy salary, and plenty of time for study, I exhort him to shun the thought as the emanation of an immature brain. There are no such positions going. Good salaries there are in exceptional cases, but genera:ly these are over-earned, and with the increase of responsibility there comes an ever increasing lack of opportunity to do more than keep up with existing engineering practice. I do not think I am exaggerating when I say that the opportunities for the young man are at the present time unparallelled. I therefore earnestly counsel him to lose no time in entering into his heritage, and to remember that even though there may be, in many cases, difficulties in the way of taking the fullest advantage of the University course, that Institution will most certainly fulfil very completely the aim of its founders, namely, the general dissemination of knowledge, and that there will be an abundance of crumbs to be picked up by any man who is really hungering after knowledge.

It is, as a matter of fact, at this stage impossible to realise the effect that this new departure will have upon the culture and learning of Western Australia. The work is being started on such broad lines, and has been placed in such competent hands, that it is certain that the State must reap incalculable benefit.

As a last word, I would point out that we are now fully equipped, and that it depends largely upon the members of this Institution, as to the place that Western Australia will maintain in the engineering world of Australia.

We have as our field of operations about one-third of the continent a great proportion of which is virgin country, but which is undoubtedly already proved to be extremely rich in its varied resources.

We are closer in touch with the engineering centres of the world than any other part of Australia (possessing as we do the maritime outlet, which is allowed by all thinkers to be the future gate of Australia), we have the able assistance of many experts who represent allied professions and who have in the past rendered signal service in connection with our undertakings, and we are untrammelled to a very great extent by old established practice and custom.

In view of all our opportunities and proved performance, do I lay myself open to any charge of presumption when I point to the top place as being within the easy reach of the engineering profession of this State ?

EARTH PRESSURES AND THRUSTS IN RETAINING WALLS. *

(By Alfred Tomlinson.)

Although this paper deals particularly with " Earth Thrusts in Retaining Walls" (structures for sustaining the lateral pressure of earth deposited behind them) the results obtained are closely associated with those in trenches, tunnels, and the like. Generally, the physical character and condition of earth, the relative geological position and the effect of the impairing elements are all so very variable and numerous that there are few, if any, earths in which the angle of slope, cohesion, weight sustaining power, ability to resist the action of water and meteorological influences, are the same at all depths—the different conditions and arrangements in which they are found being almost infinite.

It appears, at the outset, impossible to obtain a mathematical expression that would embody all these varying uncertain elements. Undoubtedly the general question of earth pressure is very complex, even abtruse, although in actual practice engineers in designing, and contractors in executing, works do not neglect them, but allow for them to some extent in a " practical " way. Now the problem, in the case of an ordinary retaining wall, is not so complex, although it is still difficult enough to solve, for ordinary retaining walls have a backing that is approximately homogeneous throughout. This is the condition assumed in this paper. The manner of depositing the backing also affects the earth thrust. If dry clayey material is loosely deposited behind the wall it will exert full pressure due to that condition. In time the clayey earth becomes consolidated—cohesion and moisture making a solid earth which, it is believed, produces a very different thrust to that ordinarily assumed. This effect is produced immediately if backing is laid in layers well rammed. Again, due to the effects of the elements, the back may shrink away from the wall so that no pressure will be exerted at all. On the other hand, if a considerable amount of water is absorbed by the backing the thrust approaches that due to a liquid. Evidently, for the design of a retaining wall to have a theoretical basis, a particular condition of the backing must be obtained which produces an actual maximum effective lateral pressure. This pressure can then be obtained rationally, otherwise " rule of thumb " methods of design will prevail. As far back as the year 1881 the late Sir B. Baker stated that,† "the mass of existent literature on the subject is both misleading and disappointing

* For diagrams see end of book.

† Proceedings, Institution of Civil Engineers (London), Vol. lxv—iii, p. 5.

for, with little exception, the bulk of it consists merely of arithmetical changes rung upon a century old theory, which, even at the time of its inception, was put forward but as a provisional approximation to the truth, pending the acquirement of the necessary data" ; in other words, "at its inception the theory was known to be untrue."

The same may be said to-day, for the same theory is in general use, although, during the last few years, an attempt has been made to reconcile the ordinary theory with practice, with apparent success, although few designers appear to make use of it. This may be due to this corrected ordinary theory not being generally known, or owing to the prevalence of "rule of thumb" methods its existence is ignored The common use of "rule of thumb" methods is undoubtedly due to the fact that the results obtained by this ordinary text book theory, as should be expected, by no means coincide with actual results, to the just discredit, with its consequent distrust and disappointment, in theory. Now nearly all theorists have considered earth to be a homogeneous granular mass, held in place by the friction of the particles on each other, and, with a few exceptions, without cohesion. This results in a uniformly varying lateral thrust zero at top, say, and greatest at base of wall. This condition has been assumed by theorists owing probably to the complexity of the subject and also because—and this is important—it has evidently been taken for granted that if cohesion, or adhesion, is taken into account, its effect will be merely to reduce the magnitude of the thrust. From the results of some minor experiments in 1906, which coincide practically with those of Mr. Meem* (Appendix 3), and from subsequent experience and evidences of earth pressures everywhere, the author believes that this condition is not borne out in actual practice, that, briefly, cohesion affects the distribution and the position of the resultant thrust.

Now, it is difficult to measure the actual earth pressure at the back of a retaining wall, due to practical difficulties, such as the recording apparatus producing local disturbances ; in other words, abnormal conditions. Again, the failures of walls, in practice, owing to them almost invariably failing through the foundations giving way, through the presence of excess of water, furnish no true record of the actual pressure of earth. However, the behaviour of the struts in trenches, and the like, affords a ready available true indication of the lateral pressure of earth. In a paper by Mr. J. C. Meem* "it was maintained, as the result of great experience, that all closely sheeted, well braced trenches invariably show a heavier pressure at the top than at the bottom."

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* Proceedings, American Society of Civil Engineers, Vol. LX. p. 5.

Cohesion, it is maintained, alters the position of the resultant thrust besides, as is generally considered, merely reducing the magnitude, and is consequently an important factor. Most experimentalists, particularly laboratory, dealing only with comparatively small walls, have failed to discover this dominant factor, owing to the fact, as seen later and in Appendix 3, that conditions analogous to those in actual retaining walls have not been used or carried out in the experiment. They failed to recognise that in small experiments the backing material, generally sand, should be weighted so as to reproduce actual conditions. Hitherto, as stated before, amongst the well-known theories, a granular mass without cohesion, what may be called "hypothetical earth," it is believed, only has been dealt with. Now, theory should be the result of practical experience, experiment and research.

It is proposed, so as to try and deal with actual earth and attempt to reconcile theory with practice, in other words, to theorise on a practical basis, to divide backing materials into two groups, thus :—

Group 1. GRANULAR MATERIALS, similar to sand, considered to be either so dry, or so saturated with water, as to flow.

Group 2. ORDINARY CONSOLIDATED EARTH.—Clays, loams, moist sand, etc., possessing adhesion and cohesion, with rigidity; which will stand, for a time, with a vertical face.

These groups will first be considered separately and attempts made to establish laws, in each group, for determining the earth thrust and the resulting thrust in the retaining wall. It will be noticed that material such as solid rock has been omitted, for such materials, being sufficiently rigid themselves, produce no thrust, except when fragments are detached. In this case the design would be for a face wall and not a retaining wall. In the groupings just given it is important to realise that material in Group 2 may, through the action of water, be so transformed as to come under Group 1. *In what follows, walls of unit length, having vertical backs only, are considered.* The latter is simply to avoid unnecessary complication. (See Note II, Appendix 2).

GROUP 1.

GRANULAR MATERIALS (similar to sand), which flow, possessing no adhesion or cohesion.

Here the ordinary theories of earth pressure will be dealt with, for the material specified is the same as for this Group 1. Rankine found, and it is usual to maintain, that the earth pressure

varies directly as the depth and therefore similar to a fluid pressure, and so the theories in this group are often named the fluid theories To determine the pressure of the filling or backing on the wall it is necessary that the resultant pressure be known :—

(*a*) In amount.

(*b*) In direction.

(*c*) In point of application.

Many theories have been proposed for finding this pressure, each differing somewhat in the assumptions as to the directions. Thus, amongst others :—

1. Rankine (and Weyrauch) assumes the filling, being of indefinite extent, to consist of an incompressible homogeneous granular mass, without cohesion, the material behaving like a fluid. The theory, which is well known, introduces the " ellipse of stress " and fixes the direction and position of thrust, viz. : that the resultant thrust is parallel to the upper surface and acts at a point ⅓rd height from base. (Weyrauch assumes that this height=2-5ths from base.)

2. Coulomb (or Wedge) assumes that there is a certain wedge, having the wall as one side, and a plane called the rupture plane as the other side, which exerts more thrust, in any particular direction, than any other wedge. Some critics say that this theory distinctly akes cohesion into account, and could not be applied to granular materials, but the majority of authorities state that it applies only to cases of purely frictional resistance, without cohesion. In Figure 1, *AC* represents a vertical wall with earth filling behind, *AB* being in the direction of the angle of repose. The only portion which presses against the wall is the wedge *ABC*, but, as is easily seen, the pressure which the whole prism *ABC* produces is actually less than for a certain portion of it, say, *ADC*. As the wall must be stable under the most adverse conditions, it is necessary to determine the particular prism *ADC* which produces the maximum thrust. This depends, other things being equal, on the direction (angle) of the resultant with normal to back of wall. Thus with a certain direction of resultant thrust *ADC* will give the required thrust, while AD^1C determines this maximum thrust for some other direction. This wedge theory does not determine either the direction or the position of the resultant thrust, and leads to many other theories having assumed directions, the position of the thrust being customarily fixed at ⅓rd height from base. What is generally called Coulomb's thrust, however, is the one normal to back of the wall.

The following are based on this Wedge theory :—

(*a*) *Cain's* (*and Rebhann's*).—Assumed that the resultant thrust makes an angle, with the normal to back of wall, equal to B^1, the angle of friction of backing on the back of the wall, or equal to B, angle of repose of backing, if $B^1 > B$.

(*b*) *Scheffler's*.—Here the direction is B, angle of repose of backing, to the horizontal.

(*c*) *Other Authorities* take an average result and so assume that the direction, with normal to back of wall, is $B/2$.

There appears, then, to be two main theories, based respectively on those of Rankine and Coulomb. On looking into most text and pocket books on the subject it will be found that these theories are treated quite distinctly, as if there existed no connection between the two. However, from Appendix 1, it will be seen that Rankine's result is merely a particular case of the more general Wedge theory, which will now be considered.

In Figure 1 symbols, B=angle of repose of earth, C=angle of surcharge, A=angle of thrust with normal to wall, h=vertical height of wall in feet, w=weight of a cubic foot of earth, P= maximum thrust in direction A.

The three forces acting on the wedge ADC, AD being considered to be the rupture plane, are as follows :—W the weight of the wedge ADC, R the reaction of the plane of rupture, acting at an angle with the normal equal to the angle B of friction, P the earth thrust against the wall AC. Now, by considering the equilibrium of this wedge, it is found that the maximum earth thrust in direction A,

$$P = \tfrac{1}{2}wh^2 \quad \frac{\cos^2 B}{\cos A \left\{ 1 \quad \sqrt{\dfrac{\sin(BA)\,\sin(B-C)}{\cos A \cos C}} \right\}^2}$$

Assuming the pressure to vary as the depth, the position of this thrust is ⅓rd height from base. By inserting particular values of A, all the results of the theories dealt with are obtained, as shown in Appendix 1. (See also Note II, Appendix 2.) The formulae obtained by the theorists is, then, for this maximum thrust always of the form, $P = \tfrac{1}{2}wh^2 \; K$. Where K is a constant, in any particular case, depending on angles only, being quite independent of w or h. Before proceeding to consider the differences in the values obtained by the various formulae, it will be well to look into the graphical results of this Wedge theory. In Figure 1, for wedge ADC to produce the maximum thrust in direction A it is found that the triangle ADC must equal in area

the triangle ADF, or, $CE = DF$. In Appendix 2, describing the graphical construction, based on this result, only one method is given (Figure 2), namely, that due to Rebhann, and where P=weight of unit volume of backing multiplied area of triangle HDF. This construction fails when $B = 45°$ (or over), for CK coincides with CB, and evidently D is the middle point of CB.

In dealing with granular material, B is generally less than 45°, so that Rebhann's construction can be used; however, when the material is cohesive this angle, as will be seen later, may be greater than 45°. The author suggests that the new graphical method, as given in Appendix 2 (Figure 3) be used for angles over 45°, the proof of which is not difficult. From the foregoing it appears that great differences of opinion exist as to the inclination of the resultant thrust, and consequently the results by no means agree with one another, and it is difficult, by merely glancing over these results, to know which to take or use.

Figure 4 shows these different theories, taking the earth to have a horizontal surface, the equilibrant, or thrust in retaining wall, being assumed to be equal and opposite to the earth thrust. Now, Rankine obtained the direction of the thrust and found, as stated before, that it acted parallel to the upper surface. The Wedge theory does not fix any direction, so that Rankine's direction is probably correct. This can be proved in another way. In Figure 5 the pressure, and consequently the friction, varies as the depth; the three forces P, W and R must meet in a point for equilibrium; it follows, since P must pass through point ⅓rd height AC, that inclination of P must be parallel to surface CB. The directions assumed by Cain and others then appear to be wrong. Now, as before stated, in comparing this result (Rankine) with those obtained from actual experience a serious difference is noticed. Thus, as pointed out by the late Sir B. Baker, in the case of a retaining wall with upper surface of earth horizontal, assuming the backing to be granular, that, taking the ordinary formula of Rankine or Coulomb, and designing accordingly so that wall is just on the point of overturning (factor of stability is unity), that, in actual practice, the wall will have a factor of stability of 2.

As ordinarily enunciated, Rankine's and Coulomb's theories are defective, and this is probably because they fail to take into account friction on the back of wall. Prof. Boussinesq* developed Rankine's formula, taking friction on the wall into account, but his results are complicated and are not used in ordinary practice. On looking into the boundary conditions—between the face of

* Proceedings, Institution of Civil Engineers, London, Vol. LXV, p. 76.

wall and the filling itself—in order for the thrust, due to earth, to be transmitted and balanced by the wall thrust, it is necessary for it to act across this boundary surface, and this must produce friction. In other words, it is impossible to apply a force to keep the wedge of earth in equilibrium without producing friction on the surface of contact. Hitherto it has been assumed that the equilibrant thrust of wall was applied to the surface of earth in the same line of action as the thrust of the earth itself. (Fig. 4.) It is now known that generally these two forces cannot have the same line of action, and consequently this wall thrust cannot be applied. This is contrary to ordinary assumption, and thus Rankine's and Coulomb's theories do not give the thrust in the wall, and so are defective, as Baker and others have found them to be.

In Figure 6 imagine a force T, in fixed direction A, applied to a weightless mass—there being friction on the contact surface —while P is the wall thrust, the direction of which varies between O° and B^{1}. Horizontal components Q of forces T and P are equal. A weight W is now placed on top of mass, and the whole will be in equilibrium, if $W = < P$ Sin $B^{1} - T$ Sin A. Since, in actual practice, weight of wedge W, the active force, will always be greater than P Sin $B^{1} - T$ Sin A—that is, excess of friction P produces in upward direction—it follows that P will have a maximum inclination (B^{1}) and a force, M, will have to be applied to maintain equilibrium. Since the active forces must always act downwards, $W - M = P$ Sin $B^{1} - T$ Sin A, is always positive, and equal to S, say. Now, although in wedge the total weight is equal to W, the effect of friction on wall is similar to applying a force S at boundary, the weight of the wedge being $W - S$. Taking friction into account, as will now be seen, does not really complicate the result.

* In Figure 7, consider the forces at the boundary AC. P and T require force S to keep them in equilibrium and these forces form a closed triangle *abd*. Consider now the forces in the wedge itself. Vertical force $W - S$, earth thrust T, and reaction R form a closed triangle *dbc*. These two triangles of forces may be added together to form the one triangle *acd*. The effect of the thrust T, in earth, being merely that of a strut, it can be ignored, and the problem reduces itself to finding the thrust P, when the inclination is at a certain angle B, the angle of repose or angle of friction of backing on wall. This result coincides with that of Cain or Rebhann (or Scheffler, with vertical walls), so that if it be understood that instead of finding the thrust in

* The proof is based on the generally accepted lines. However, it should be noticed that it is really taken for granted that the backing acts as if it was all in one mass, in other words behaves like a solid.

earth itself, as Cain, etc., found, the thrust in wall is being considered, this formula gives the correct result when friction at back of wall is considered. It appears, then, that Rankine obtains the direction and value of the thrust in earth itself or on an imaginary section, a formula similar to Cain's giving the thrust in the wall, on a material section, to withstand this earth thrust. The effect of taking friction into account does not materially alter the magnitude of the thrust, its greatest effect is to deflect the thrust downwards and so produce less overturning moment.

Some authorities object to this frictional resistance being taken into account, for it is maintained, if the back of wall is wet there cannot be any friction. This is never true unless there is a column of water between wall and backing, and then water pressure would be dealt with and not earth pressure. Besides, in ordinary practice, rubble backing, with weep holes (ample drainage) is provided, which has a considerable angle of friction (30°) against back of wall, even if very wet. Applying this result (Cain's formula) to actual examples it is found to give reasonable results. Thus, weight of earth = 120 lb. per cubic ft.

$$B = A = 30^\circ. \quad C = O.$$

Whence, $P = 17.85\ h^2$ lb.

Or, $\begin{cases} \text{Horizontal Component of } P = 15.45\ h^2 \text{ lbs.} \\ \text{Vertical Component of } P = \ \ 8.92\ h^2 \text{ lbs.} \end{cases}$

Applying these figures to an ordinary retaining wall of masonry at 120 lbs. per cubic foot, and assuming that resultant goes through middle third, is it found that thickness at base $= {}^2/_5 \times h$ approximately, which is usual practice and coincides approximately with Baker's result (liquid 20 lbs.).

The next three examples, Figures 8*a*, 8*b* and 8*c*, are taken from experimental walls given by the late Sir B. Baker in his paper on earth pressures :—

Figure 8*a*.—General Burgoyne's experimental wall. "*The wall tilted over gradually, broke across and fell forward.*" The wall was of granite, 142 lbs. cubic foot. The backing of earth at 112 lbs. per cubic foot. $\text{Tan } B = \frac{1}{1\frac{1}{2}}$

Figure 8*b*.—Noticed by Baker. "*The stacked wooden block wall was stable.*" Wall was of pitch pine at 46 lbs. per cubic foot. The backing of old macadam at 101 lbs. per cubic foot. $\text{Tan } B = \frac{1}{1.2}$

Figure 8c.—Hope's experimental wall. "*Wall fell forward in one mass.*" Wall was of brick at 112 lbs. per cubic foot The backing of ballast at 95 lbs. per cubic foot.

$$\text{Tan } B = \frac{1}{1\frac{1}{3}}$$

The results are clearly shown on the diagrams. Assuming that the backing material is granular, as in this Group 1, it is found that the results obtained by Cain's formula, or Rebhann's construction, agree with what actually happened in practice, the ordinary theories giving untenable results. Evidently the discrepancy noticed by Baker and others between thrusts obtained by Rankine and Coulomb and those "in practice" is, if the material is purely granular, due to the fact that friction at back of wall had been neglected. A formula similar to Cain's may be looked upon as representing the corrected ordinary theory, and to comply with actual practice it is necessary to use this formula to obtain actual thrust in wall itself. For ease and speed, curves—as in Figure 9—may be drawn, showing the relation between B, A and K, so that, knowing B and A, K can easily be obtained, whence the value of P is known, for $P = \frac{1}{2}wh^2 \times K$.

Roughly, for ordinary purposes, for any ordinary angle A,

$$K = \left\{1 - \frac{B+15}{100}\right\}^2, \quad B = \text{Angle of Repose.}$$

So if $w = 100$ lbs. and h is in feet,

$$P = \tfrac{1}{2}h^2 \times \left\{8.5 - \frac{B}{10}\right\}^2 \text{ lbs.}$$

Group 2.

Materials Having Cohesion.—In general, consolidated materials, such as loams, clays, moist or wet sand (not saturated), ordinary earths.

As mentioned before, in the beginning, few theorists have taken cohesion or adhesion into account. For, it was thought, its only effect was to reduce the magnitude of the lateral thrust, and, being a variable quantity and having to design for the worst conditions, its existence was conveniently ignored.

In Figure 10, suppose BCA is the shape of a mass of earth, cohesion just being sufficient to prevent the mass from altering its shape. The prism of earth is acted upon by three forces, thus:—The weight W of the prism ACD^1; R, the reaction of the plane of rupture, acting to oppose sliding, with an angle to the normal, equal to the angle B of friction; the cohesion, acting along AD^1 to oppose sliding. If it were not in equilibrium another force, acting against AC, to equalise the resultant earth

thrust would be required. Suppose that wedge ACD^1 tends to slip along AD^1, then it is easily proved that cohesion, K per sq. foot$=\frac{1}{2} \times w \times G^1F^1$. G^1F^1 will have different values according to direction of plane AD^1, and maximum value$=\frac{1}{2} \times w \times GF$, where F is middle point of arc CF^1E. In other words, AD gives the maximum rupture plane for cohesion when AD bisects the angle CAB. From Figure 10, cohesion per sq. foot$=\frac{1}{2} \times w \times GF$ $=\frac{1}{4} \times w \times G_2F_2$. So that, knowing maximum height and slope (friction) of a material, its cohesive value can be obtained by construction. Further, by a simple graphic method also, the height to which a given material will stand at a given inclination of face can be found, assuming, of course, that the value of the cohesion is constant throughout. Prof. Ritter obtained a parabola, Figure 11, having its focus at A, axis along AB, and directrix at a distance from A equal to EF_2, such that, on joining any point C^1, on the parabola, to the focus A a line AC^1 is obtained, the length of which is a maximum for stability at the angle D. Now the rupture plane which produces a maximum thrust, taking friction only into account, and the plane along which the cohesion has least effect in diminishing the thrust, will not, in general, coincide. These planes are separate and distinct, and the method of combining to obtain the total effect is difficult.

The author, as an approximation, assumes that, in any particular case, the friction and the cohesion may be considered to act together as a unit. In Figure 11, AB is inclination B of material for friction only, AC^1 is maximum vertical height the material would stand at inclination D, obtained, as above, by Ritter's parabola. The angle D is taken to represent the joint effect of friction and cohesion. In other words, treat the material as having an angle of repose$=D$, without cohesion, for D is the maximum angle of slope for particular height h $(=AC_1^1)$.

In Fig. 12a, using same notation as before, from Ritter's parabola point C^1 is determined. Now imagine that the greatest thrust is produced by sliding down some plane AD, the angle of "friction and cohesion" being D. It is not difficult to prove that in case of a cohesive body, if the material is cut along some plane AD, that the equilibrant wall thrust is obtained in a similar manner to that of a granular mass, as in Group 1.

Neglecting the effect of cohesion across the slipping plane, the wedge theory, then, holds for a cohesive mass. Fig. 12a.—The maximum thrust in wall in direction $A=$

$$P=\frac{1}{2}wh^2 \times \frac{\text{Cos}^2 D}{\text{Cos } A \left\{ 1+\sqrt{\frac{\text{Sin}(D+A)\ \text{Sin}(D-C)}{\text{Cos } A\ \text{Cos } C}} \right\}^2}$$

However, since D is determined easily by graphics, the graphical treatment is recommended. (Fig. 12b.)

Nothing has yet been said about the position of the resultant thrust. It is customary to assume that it acts $\frac{1}{3}$rd height from base, similar to that of materials in Group 1, and consequently, if the pressure varies uniformly, the greatest pressure will be at the base. As before stated, it is believed that this assumption is not justified in dealing with consolidated material.

Going back to the "wedge theory," for the equilibrium of the wedge, $P=\frac{1}{2}wh^2 \times K$ for granular materials (Group 1) and approximately for cohesive materials (Group 2). Then, in any particular case, P varies as h^2. If thrust varies uniformly from zero to a maximum, that is no tenson allowed in the material, this relation is satisfied if—

(1) The pressure is zero at top and maximum at base, so that resultant acts $\frac{1}{3}$rd height from base; or

(2) The pressure is maximum at top and zero at base, so that resultant acts $\frac{2}{3}$rds height from base.

It appears, then, that either position of resultant thrust satisfies wedge theory.

In the first portion of paper (Group 1) dealing with material having no elasticity of shape, the resultant acted $\frac{1}{3}$rd from base. Now, in dealing with cohesive materials which undoubtedly have elasticity of shape, the author believes that the resultant wall thrust acts approximtaely $\frac{1}{3}$rd height from top. This is, of course, contrary to the generally accepted theory (Group 1), which, however, is believed to be of little value, being, in most cases, flatly contradicted by experience with actual earths. The late Sir B. Baker said, "that the universal assumption of the pressure of earthwork being analogous to that of a fluid, and proportional to the depth, is one of convenience rather than truth." That material having cohesion has properties very different to material without cohesion is easily seen from the following simple experiments, where extreme cases are represented (Figures 13*a*, and *b*) :—

In (*a*) a wedge of dry uncohesive granular material is placed on plane at angle of repose of material;

In (*b*) a wedge of solid material is used.

Now in (*A*) a rigid lamina and a force P is necessary to preserve equilibrium, and by reasoning (Group 1) or experiment the force P is known, its position and direction being fixed. In (*B*) no force is required to hold the wedge in equilibrium. Again, another difference is noticed, when the material is supposed to slide down some plane AD. In (*A*) the position of P will again be fixed $\frac{1}{3}$rd height from height and acting base, while in (*B*) the force P, having a constant value if applied at same

inclination may be applied anywhere on the vertical surface. In this latter case it is possible to replace P by one of two sets of uniformly varying forces, so that there will be no tension or lifting tendency on the sliding surface. In one case P will act $\frac{1}{3}$rd from top, and in the other $\frac{1}{3}$rd from base.

With cohesion in ordinary earths may be associated tensile compressive and shear strengths. These are the properties of solids, although these strength values compared with those of masonry, say, may only be small. Numerous instances, a few of which will now be given, of ordinary earths behaving as if a solid and acting contrary to ordinary fluid or Group 1 theory may be found in ordinary earth works. Thus in making trenches in ordinary consolidated material, loams, clays and moist sand, it is found that practically no pressure exists at the bottom, so that the lower portion may be left unsheeted without disturbing the stability of this face, thrusts, of course, existing in the bracing above. Again, undercutting excavations can be made by the use of light poling board only, without disturbing the stability of the mass above, the face often being unsheeted. The boards have to resist pressure, but nothing like the full weight of material above, as according to the fluid theory. Mr. Meem said, " It is possible, also, at any time, to cut or remove the bottom sheeting (except in dry sand) for a considerable percentage of the vertical distance from the bottom, and for indefinite lengths, without interfering with the stability of the bank above, provided the sheeting is removed without jarring. Any practical man, however, will admit that it would be suicidal to remove any of the braces near the top of the excavation, particularly after the ground had stood for any considerable time."

Again, " Anyone who has had to do with deep trenches or tunnels realises that an exposed face of earth is under no more pressure at the bottom of the deepest trench or tunnels than it is at the bottom of a shallow one." Also, " if a trench be sunk 20 ft. and stopped, the pressure developed at the 15 ft. level will not be excessive, whereas if it be continued to 60 ft. the bracing will have to be heavily reinforced at the same 15 ft. level; and, if the trench be carried down to an indefinite depth no bracing would eventually be able to withstand the pressure at this point." It is probably unnecessary to point out that in practice, or in experimenting, the " mass " of earth must be undisturbed, for if parts of it slip or are detached, owing to careless strutting or jarring, etc., very different thrusts are produced. In Mr. Meem's bracing for trenches the sectional dimensions of the timber gradually increase from the bottom upwards (same with the wallings), there practically being no timber at the bottom.* This

* Proceedings, American Society of Civil Engineers, Vol. LX, p. 8.

system of bracing is used through sand, gravel and clayey soils. In no single instance has any failure of the lower and light braces been observed, while many instances of bending in the heavier upper braces has been noticed.

Trautwine, in his pocket-book, says that all walls tend to become vertical in spite of the batter. In slopes if the base or toe be cut off, slips might occur, the line being approximately a parabola, but they do not extend to the top of the bank. This is the cleavage plane of the material, given sufficient time, the effect of the elements will loosen the material, the cohesion approximately vanishing, so that it would ultimately assume the slope of repose; this would take place immediately if material obeyed Group 1 laws. Experimental walls often fail (Figure 8*a*) by the upper portion tilting outwards, revolving round the base. This is contrary to what would be expected if material behaved like a fluid, and the greatest pressure at the bottom. To understand the behaviour of ordinary material and to attempt to answer the question "Why the greatest pressure appears to be towards the top?" etc., it is necessary to apply the idea of "arching."

Now, the tendency to slide down the rupture plane, the other face being against the wall, is to cause wedging or arching. This action, it is believed, produces lines of compression, etc., which can only take place with "solid" materials. In Figues 14*a* and 14*b*, the slipping plane to produce maximum thrust being AD, while AC is the back of wall, arches, each being independent of the others, have been drawn, the maximum inclinations for equilibrium of forces on AC and AD being used. The triangle of forces for upper arch has been drawn ($P_1W_1R_1$), and this is similar to triangle of forces for the whole of the arches (PWR), the weight W being the total weight of the arches (ACV). The thrust of the arches will then vary uniformly from a maximum at the top to zero at the base. The portion CVD, in one figure, and CMU and DVM, in other figure, have apparently been ignored. It is probable that the arches below CV will carry this weight, the effect of these portions being approximately similar to increasing the density of the arches. To obtain the total thrust, then, the triangle of forces is drawn, taking the arches to have a weight equal to the weight of the wedge ADC. With a surcharge also, the effect of the earth CDD^1 may be taken to simply increase the weight per cubic foot of the arches so that the total weight of wedge ACD^1 with angle D will give approximately the required result. Of course, owing to the probable formation of earth cantilevers across AV, VD and DD^1 the actual thrust will be less than that calculated on the above basis.

It is seen that the total thrust is approximately the same whether arching is considered or not, for the triangle of forces is similar to that obtained before, in Group 1, and in the early part of this Group 2 (*i.e.*, before the position of the resultant was considered). Thus the effect of wedging and arching action may be taken to simply alter the distribution of the thrust, the resultant acting ⅓rd from upper surface, approximately. This arching is easily realised if the arches are first supposed to be built of masonry, independent of each other, the masonry then to gradually lose its relative great compressive and shearing strength until it assumes the values for ordinary earth. It may be argued that arching can only take place with actual movement or motion. For it is not difficult to see that if the wall actually yielded or moved slightly forward that the backing would tend to arch itself. A similar result would be expected if water, in passing through the weep holes, carried away a little of the backing, or if tidal water in re-gaining its normal level produced settlement. Again, if Group 1 laws are supposed to hold good at the commencement, that is pressure varies directly as the depth, the material at the toe would be greatly stressed, its baulk would be reduced, and slipping would be prevented by the material above arching against the back of the wall. Of course, it is understood that arching only takes place when there is a resistance for the material to act against, such as a wall or trench sheeting.

Undoubtedly the wall has a tendency to move forward, and it is the maximum effective set of forces which this tendency produces that are to be dealt with and to be allowed for. Generally when dealing with structures that are designed to be in equilibrium, obviously there is no movement. The tendency for movement is recognised, however, and the forces to maintain equilibrium obtained, and the structure designed to safely withstand these forces. The tendency of the wall is to move forward and so arching effects must be considered. Vertical arching alone has been considered, but these ideas could be extended to include horizontal arching also.

Going back to Figure 14*a*, if no friction exists at back of wall the thrust is horizontal, and by means of the graphical construction, or calculation, the total thrust (in wall) P is obtained, arching now being taken into account, this resultant acts ⅓rd from the top, it being again noticed that the magnitude of P will be the same whether arching is considered or not. If rubble backing is provided (Fig. 14*b*) or if friction is taken into account, and assuming that there is no cohesion on the back of the wall, the angle of the resultant wall thrust$=A$ (friction only) and the value of P is obtained, as above. Hitherto the line of rupture has been considered to be straight ; in actual practice, however, it is generally curved. In a slip probably the movement and

inertia of the material in slipping forward sets up a tearing action, tending and making the actual slipping plane a curve. Again, if the value of the cohesion is not constant throughout, the fracture line will be a curve. Mr. Haines, in discussion to Mr. Meem's paper before referred to, maintained that the curve of fracture in consolidated material was approximately a semi-circle. On this basis the thrusts are calculated, the maximum being at the top and varying uniformly downwards to zero at the bottom, obtaining values which, as might be expected on close study, are practically the same as those obtained in this paper. As just explained, it is believed that this curve on the lower portion of line of rupture is due to a tearing through forward movement. and so does not really represent the normal rupture plane from which the thrusts are to be determined when earth is supported and at rest. It appears to be safer and far more convenient to take the unruptured rupture plane as straight.

In the beginning of the paper material was divided into two groups, the characteristics of which have now been dealt with, and which, when summed up, give :—

Group 1.—*Consisting of material either so dry, or saturated with water, as to flow*, the vertical pressure at any point being due to the accumulative weight of all directly above it, the material acts like a fluid, the resultant thrust being ⅓rd height above base. The magnitude and direction of the resultant wall thrust can be obtained, taking or not taking friction on wall into account.

Group 2.—*Consisting of ordinary consolidated material, possessing cohesion.*—The material acts similarly to a solid, arching or wedging is produced, the resultant thrust being ⅔rds height from base. The magnitude and direction of the resultant wall thrust can be obtained, taking or not taking friction on wall into account.

Earth Backings.

The latter portion of the paper will be devoted to the general character of earths and the maximum thrusts they are likely to produce under certain conditions. In practice, the usual stipulation that the backing should be placed in position in layers well rammed produces a consolidated mass. If the material is loosely dumped at the back of wall a certain amount of cohesion exists between the particles, even if sand, the succeeding layers gradually compressing those underneath, and in time the whole may be taken as a consolidated mass. (Appendix 3.) It is noticed that Group 1 laws will not hold, for the material undoubtedly possesses cohesion, and comes under Group 2, and, in any case, the worst effect will be allowed for if it obeys these Group 2 laws. Ordinary backing comes under Group 2, and knowing, amongst

other things, the value of the cohesion, the thrust can be obtained. If the cohesive value remained constant the wall could be designed to safely withstand the earth wall thrust, but, as is well known, this cohesive value is not a fixed quantity. It is, in fact, apt to be a very varying quantity, and, in any one particular material, fluctuates greatly, depending chiefly on the effect of water on it. The thrust in wall, then, not being a fixed quantity, it remains for this thrust to be determined under ordinary and adverse conditions.

As would be expected, there are apparently two limits between which the actual thrust will have some intermediate value. The upper limit is when the cohesive value is great, $D=90°$, there being no thrust. The lower limit is when $D=B$ approximately, the thrust then being a maximum. The word approximately is used because a difficulty arises as to the value of the least amount of cohesion necessary for "arching" to be produced. The effect of water on the backing material will now be considered, for it will be found to have an important bearing on this question.

Previously, to obtain a conception of "arching" the arches were supposed to be of masonry, this material afterwards to gradually lose its cohesive strength until, ultimately, ordinary backing material would be reached. It is not difficult to follow out this idea from masonry to rubble, to loose rock, to gravel, to moist sand, and, finally, to ordinary dry sand. Consider now the effect of water on the arching, the material first being supposed to be *insoluble in water*. The water would not disturb the arching, and, as will be seen later (Appendix 3), the effect of water, up to saturation point, is to produce adhesion or cohesion between the grains, or individual masses; this is equivalent to increasing D, and so lessens the lateral thrust. At saturation, the grains would still remain in contact with each other, the water would be continuous throughout, always directly connected with the surface, the "earth" being regarded as the material part of a series of irregular tubes. The earth grains would exert a thrust due to arching, while the water would produce an aqueous thrust on the wall, corresponding to the percentage area of solid grains pressing directly against it. It appears, then, at saturation, that the action of earth and water are quite separate and distinct. In other words, the action of each is independent of the other, so that they do not act as a unit. As stated before, moisture produces an adhesive action and so just before saturation, since then very little adhesion exists, practically the lower limit thrust is exerted ($D=B$). *If the backing* is soluble in water, or held in suspension, evidently arching is impossible, if there is a sufficient amount of water present to produce this physical condition. This mass would be like mud and flow, their being no continuous

contact of solid grains, the thrust being obtained by aqueous laws. Before saturation, when arching is possible, it is unlikely that the lower limit thrust ($D=B$) would be produced. Of course, actually in the state approaching saturation the foundations of the wall would be unstable, and the wall would as originally designed probably slide forward.

In general ordinary backing will probably consist of a mixture of the two backings just considered. Before saturation, the liquid binds the solids together so that D is increased by this addition of water, the whole acting like a solid and arching. At saturation, the solids are still arched, but weigh less owing to them displacing the solution, so that the thrust is reduced. The liquid, acting independently, exerts an aqueous thrust calculated on the specific gravity and also on the percentage of area of solid arching grains, pressing against the surface to the whole surface itself. It is probable, however, that this percentage is small, for total area of contact surfaces of solids with wall is very small, so that it is better to assume that the full hydraulic pressure is exerted. Moreover, if number of insoluble grains present be small, so that they cannot form continuous links, arching is impossible, and the thrust will be calculated on the specific gravity of the liquid only, for the grains may be considered to be merely disconnected voids. The material clay has very peculiar properties and probably occupies a place by itself. The action of air alone causes it to expand and consequently produces great lateral thrusts, which are not obtained, of course, by theory. This property, and its contraction on drying, induces fissures and cracks through which water can trickle, notwithstanding the fact that the surface of clay may be almost impermeable. The surfaces of these cracks become soft, and slimy beds are produced, the mass tending to slide down these planes of weakness. The material may have considerable cohesive strength, arching resulting, or have little strength and act more like a fluid.

That dry sand, and even sand saturated with water, does arch, apart from practical evidences everywhere, will be clearly seen from the particulars given in Appendix 3, whence it appears these sandy arches partake somewhat of the nature of a coherent solid, not because of the internal cohesion altogether, but because of the external pressure, which gives it coherence. This external loading of the sand to represent a mass of sand above it, so as to make the conditions similar to those obtained in actual practice, appears to have been neglected by nearly all experimenters. This, it is believed, is the cause of arching not being recognised before.

It is evident that if the character of the backing is known the maximum thrust can be found under any given condition. Generally an ordinary retaining wall is not designed for the saturated

condition of backing, for, as is well known, the usual failure of a retaining wall is due to the foundations giving way, the wall slipping forward and collapsing, due primarily to excess of water around the foundations.

Again, in a city rainfall is taken care of by drainage systems, the surface being impervious, and omitting accidental occurrences such as the bursting of a water main, the earth may be taken to be never wholly saturated. In open country, partial saturation may take place after a heavy rainfall, and so tend towards producing a mixture of earth and water pressure. Yet it is improbable that complete saturation is ever reached, especially if weep holes, etc., are provided.

Again, it is unlikely that the change in the value of the cohesion is the same throughout. Rather would it tend to vary uniformly downwards or from the bottom upwards. This would result in a less total effective thrust, for the position of the thrust would be somewhere below ⅔rd height above the base, or reduced in magnitude.

All this and other evidence shows that, generally, the lower limit thrust ($D=B$) the maximum, is a rare occurrence in practice. It is even improbable that this thrust ($D=B$) could exist, still the maximum thrust tends to reach this value and so must be considered. It appears that if the retaining wall were designed so that it would just be stable under this maximum thrust, it would have, in all probability, an ample factor of safety under ordinary conditions. The author suggests, then, that this lower limit, $D=B$, thrust be used in designing walls under ordinary conditions, the factor of safety or stability being unity. It must be understood, however, that if on looking into the character, etc., of the backing it is found that this maximum thrust is likely to be produced that a greater factor of stability should be allowed for and resultant thrust on base made to comply with the middle third or similar rule. The method of design is as follows (Fig. 15). Obtain, either by the Group 2 formula or curve diagrams similar to Fig. 9, or by graphical construction, the total earth wall thrust P, taking angle of friction $= B$. This is taken as acting ⅓rd of height of wall from the top, and in a direction of angle of friction to normal to back of wall. Then by calculation, or by graphics, knowing the weight of the wall per unit volume, the thickness AE of the wall may be obtained so that the resultant of the earth wall thrust and the weight of the wall will just pass through the toe E of the wall.

In the design of an ordinary retaining wall it has just been taken for granted that ample factor of safety would be produced if wall was designed to just be stable under lower limit ($D=B$) thrust. To test the reasonableness of this assumption, the walls given at end of Group 1, Figs. 8*a*, 8*b* and 8*c*, will first be utilised,

the backing now supposed to have cohesion and "arch." (Figures 16*a*, 16*b*, 16*c*). In Group 1 it was seen that these walls just complied with the experimental results when the backing was assumed to be purely granular, and friction at back of wall taken into account. Here resultant P acted $\frac{1}{3}$rd height from base, and if now the resultant is moved so that it is $\frac{2}{3}$rd height from base, then it will be necessary for the thrust P to be approximately halved, in order that the walls may behave similarly. Using these same three experimental walls, the backing to arch itself, the following approximate values are obtained to fit in with actual results :—

$$\left.\begin{array}{ll} \text{Fig. 16}a. & B=34^\circ,\ D=51^\circ \\ \text{,, 16}b. & B=40^\circ,\ D=60^\circ \\ \text{,, 16}c. & B=37^\circ,\ D=53^\circ \end{array}\right\} \text{or roughly, } D=\tfrac{2}{3}B+28^\circ.$$

This same result may be obtained directly by finding a value for D in terms of B such that the value of K will be about halved, from the approximate formula, $K=\left\{1-\frac{B+15}{100}\right\}^2$, given at end of Group 1. So if $B=30^\circ$, the average angle of repose of ordinary materials, then $D=45^\circ$, about, and if $B=33^\circ$, $D=50^\circ$. In reference to the cracks on some 34 miles of deep timbered trenches and tunnels, the late Sir B. Baker* said "The slope of these fissures was so uniformly at the angle $\frac{1}{2}$ to 1 measured from the bottom of the excavation, that the Resident Engineer professed to be able to foretell with certainty where a building would crack most." Mr. Haines† also noticed the same $\frac{1}{2}$ to 1 rupture line in ordinary consolidated material.

This $\frac{1}{2}$ to 1 rupture line, taking angle of friction to be 30°, gives a similar result to what has just been obtained from the experimental walls, namely, $D=45^\circ$ approximately. This is equivalent roughly to saying that generally the cohesive value of backing is such that "up to a height of 5′ 0″ the backing must remain vertical for a height of 9″," thus :—

Up to a height of	5′	the backing must remain vertical for		a height of	9″
Do.	10′	do.	do.	do.	1′ 0″
Do.	20′	do.	do.	do.	2′ 0″
Do.	30′	do.	do.	do.	3′ 0″
Do.	h	do.	do	approx.	$\frac{h}{10}$

This result appears to be reasonable.

It will be found that on designing a wall so that factor of stability is unity, on the lower limit thrust, $D=B$, that this probable value of the cohesion enables the resultant of weight of

* Ibid p. 21.

† Proceedings, American Society of Civil Engineers, Vol. LX, p. 27.

wall and thrust in wall to pass within the middle third of base. In figure 15 (no surcharge) the resultant complies with ordinary relation of thickness of wall and height. ($B=30°$, $b={}^2/_5 \times h$). Again, if rubble backing is assumed and the wall, designed in an extreme case ($B=20°$) so that it will just be stable as regards overturning ($D=B=20°$) it complies with the middle third rule when the ordinary cohesive value, as obtained above, is assumed. ($b={}^2/_5 \times h$.)

In the above two cases the weights of the backing and the wall have been assumed to be the same, actually, the wall will be the heavier per cubic foot, so that the actual results are more favorable than those given above. This method of designing a wall appears to be reasonable and since arching is taken into account, the worst effect has been included.

Walls, then, should be designed, in ordinary cases, for a factor of stability=1. As pointed out before, and so that no mistake will be made, it is again stated that if it is known that the earth backing is liable to be completely immersed in and saturated with water the resultant of the thrust due to the earth and to the water should be allowed for in designing the wall. It is interesting to note that Mr. Haines, by different reasoning, obtained the formula $P=\frac{1}{2} \times wh^2 \times .275$, for the actual resultant thrust, the angle of repose of material being 33° (which exactly corresponds with that obtained by the Author) this thrust acting $\frac{2}{3}$rd height from base. This result is about half that obtained by Mr. Meem, who, however, recognised that his pressure was too great.

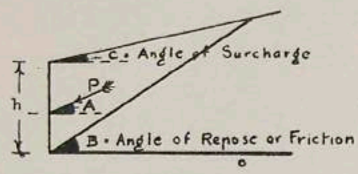
In Conclusion.—Ordinary earth may be conceived to be in a state of ease, the pressure varying as the depth, but on a trench being cut through it and properly sheeted, this normal state is disturbed, abnormal conditions are produced with resulting "arching or wedging." Through a similar discontinuity the earth in the immediate vicinity of a retaining wall does not obey the fluid laws, but inverses them, in fact, through this arching effect. Backing materials were divided, at the beginning of the paper, into two groups for convenience:—

Group 1, *dealing with a theoretical condition of matter* (or what could be called hypothetical earth), as regards wall thrusts, is now known to be really of academic interest only. The pressure at the back of a wall, or sheeting, is not cumulative vertically when dealing with ordinary backing material. Again, in the case of running sand and the like the pressures are hydrostatic and not earth. However, if the backing satisfies the conditions of Group 1 materials the laws, etc., as obtained are correct, although the apparent reconciliation with practice, by assuming friction at back of wall, is believed to be only a coincidence. It may be

argued, since walls designed by this corrected Group 1 method generally do not collapse in practice, that the theory is correct. It is believed that this is no absolute criterion as to whether the existing theory is right or wrong, for it has been adjusted or made to fit in with ordinary practice. *Ordinary backing undoubtedly possess cohesion, and the principle of arching must be recognised as the dominant property, and so Gronp 2 results must be used in design.* From the results it seems that in masonry retaining walls, the design and stability of the structure is about the same whether Group 1 and middle third rule, or the new Group 2 theories are used. However, this arching theory will probably account for some of the failures universally attributed to faulty foundations. The ordinary masonry wall is able to retain earth behind it, owing primarily to its weight. A ferro-concrete retaining wall, on the other hand, depends for its stability, apart from its strength, on the arrangements of its component parts. Owing to the much greater relative cost of ferro-concrete, the actual thrusts require to be more carefully considered than is necessary with ordinary masonry wall designs. In a reinforced concrete retaining wall, the different theories give different results as regards the face of the wall. However, in actual construction, owing to practical considerations, the arching theory will not greatly affect the design, as ordinarily carried out.

Finally.—In this paper the author wishes to impress what is believed to be a fact, namely, that the ordinary theory is based on wrong assumptions, for ordinary materials, and that the true result can only be obtained by considering the material to behave like a solid, with resulting " arching."

Appendix I



P = Max. Thrust in Direction 'A'.

w = Weigh of Unit Volume of Backing.

Wedge (General Theory)

$$P = \frac{1}{2}wh^2 \times \frac{\cos^2 B}{\cos A\left\{1 + \sqrt{\frac{\sin(B+A)\sin(B-C)}{\cos A\cos C}}\right\}^2}$$

Rebhann & Cain (A = B')

$$P = \frac{1}{2}wh^2 \times \frac{\cos^2 B}{\cos B'\left\{1 + \sqrt{\frac{\sin(B+B')\sin(B-C)}{\cos B'\cos C}}\right\}^2}$$

Rankine (A = C)

$$P = \frac{1}{2}wh^2 \times \frac{\cos^2 B}{\cos C\left\{1 + \sqrt{\frac{\sin(B+C)\sin(B-C)}{\cos^2 C}}\right\}^2} = \frac{1}{2}wh^2 \times \cos C \times \frac{\cos C - \sqrt{\cos^2 C - \cos^2 B}}{\cos C + \sqrt{\cos^2 C - \cos^2 B}}$$

Coulomb (A = 0)

$$P = \frac{1}{2}wh^2 \times \frac{\cos^2 B}{\left\{1 + \sqrt{\frac{\sin B\sin(B-C)}{\cos C}}\right\}^2}$$

Rankine (A = 0, C = 0)

$$P = \frac{1}{2}wh^2 \times \frac{\cos^2 B}{\{1 + \sin B\}^2} = \frac{1}{2}wh^2 \times \frac{1 - \sin B}{1 + \sin B}$$

APPENDIX II

Rebhann's Construction (Figure 2) when B is less than 45°. Draw CK making angle $CKB=90°+A$. On AB as diameter draw semicircle AGB. Form K draw KG perpendicular to AB, cutting circle in G. With A as centre and radius AG draw arc GF, cutting AB in F. Through F draw FD parallel to CK, cutting CB in D. Join AD. Then ADC is the required wedge, and AD the rupture plane, to produce the maximum thrust in the " direction A " to normal to back of wall. The proof of this is similar to that given below in the New Construction. The same result is obtained in a similar way to the above if semicircles are drawn on AC or CB as diameters.

Again, in figure, $FH=FD$. Join HD. Then HDF is called the earth pressure triangle. P=*the total thrust in direction* A= area (in sq. feet) $HDF \times$ weight cubic foot of backing. By construction, area HDF=area VFC, so that the intercept on the triangle $VFC \times w$ will give the actual thrust at any particular height.

New Construction (Figure 3), when B is greater than 45°. Draw CK, making angle $CKB^1=90°+A$. On AK as diameter draw semicircle AGK. From C^1 draw C^1G perpendicular to AB^1. With A as centre make $AF=AG$. Through F draw FD parallel to CK cutting CB in D. Join AD. Then ACD is the required wedge and AD the rupture plane. Again making $FH=FD$, and joining DH, *the triangle* $HDF \times w$=*total thrust* P.

Proof (*Geometrical*) (Fig. 3).—In figures, since ADF is similar to triangle of forces $A_1D_1F_1$, $\frac{P}{W}=\frac{DF}{FA}$ Also, W=area $ACD \times w$. Hence :—

$$P=\tfrac{1}{2}w \text{ Sin } (90°-C) \times \frac{AC \times CD \times DF}{FA}$$

Now P varies with the angle x, required to find the maximum value of P? Considering now the triangle CC^1K, the above expression may be written :—

$$P=\frac{w}{2}\text{Sin}(90°-C) \times \frac{AC \times CK \times CC^1}{(C^1K)^2} \times \frac{C^1F \times KF}{FA}$$

Now, $\frac{C^1F \times KF}{FA}$—the variable quantity—is a maximum when $AF^2=AC^1 \times AK$. The graphical construction just given depends on this fact. From the construction it can be proved that $EFDC$ is a parallelogram. $EF=CD$, so that area ACD=area ADF.

Hence $P=w \times \text{area } ACD \times \frac{DF}{AF}=\frac{w}{2} \times AF \times DF \times \text{Sin}(90°-A) \times \frac{DF}{AF}$

$=\text{Area } FHD \times w$.

NOTE I.—When the angle of surcharge coincides with the angle of repose, or friction, this slope of repose is the rupture plane (*i.e.*, when $B=C$). The earth pressure triangle would then be the triangle CKA if KA is made equal to CK.

NOTE II.—If back of wall is inclined at angle E with the horizontal, measured in the same way as the angles B and C, then in above constructions make angles CKB (and CKB^1), DFB (and DFB^1), each equal to $E+A$, and then proceed to find P by the construction given above, it being always recognised that P can only act in a downward direction and *never* upwards.

APPENDIX 3.

CONJUGATE PRESSURES IN FINE SAND.*

The late Dr. Wilson found that it was impossible to work with absolutely dry sand, for the sand immediately absorbed moisture from the atmosphere. This moisture took the form of cohesive necks between the individual grains of sand, binding them together. Dr. Wilson also found that when the percentage of moisture or water was increased, the cohesion between the grains also increased up to a certain point, then an increase in amount of water produced a decrease in the amount of cohesion. Also that the ratio of the horizontal thrust to the vertical, at any point, in the material was practically the same when either the sand was absolutely dry or just saturated with water. (These experiments relate only to what occurs away from the vicinity of a wall, etc.)

In some minor experiments by Mr. Meem,† which are practically identical with those of the author, the arching of dry sand was clearly demonstrated. Using Mr. Meem's own words (Figure 17) :—" An 8½″ x 8½″ x 8½″ box (inside) was made, the bottom being cut away, leaving only ¾″ projections on two opposite sides, and sheer faces on the others, thus making a hole in the bottom about 8½″ x 7″. A false bottom 2″ thick and 9″ square was then made, covering a little more than the outside area of the box, and 4 No. 6″ x ¼″ bolts were run through this, and engaged with 1″ square washers and nuts as shown. It was found that absolutely dry sand would arch itself sufficiently to carry the false bottom and its own bottom load, and a superimposed load at a depth, Z, of 4½″. Dry rounded wheat grains behaved in a similar manner. A board was then inserted to represent sheeting, as shown in the figure, and the sand was found to carry itself at a depth of 4½″, showing clearly that

* Proceedings, Institution of Civil Engineers, Vol. CXLIX.

† Proceedings, American Society of Civil Engineers, Vol. LX, p. 99.

arching took place against the sheeting. Water was next introduced in sufficient quantity to allow it to steep through the crevices in the bottom, showing that sand was completely saturated. It was found that at a depth of 5″ the arching properties of the sand were such that it would carry its own and the added bottom load, together with that caused by the box being filled to the top with water."

These experiments took place, and relate to the backing in the immediate vicinity of a wall.

Discussion.

Mr. G. W. Kerslake said the author had brought before members a new theory, or at least one that from engineers had received comparatively little attention. This theory was one that could be only accepted or refuted on the result of experiments and the observation of actual walls and trenches. The author suggested, however, that our method of design should be to assume a maximum that can never be exceeded in practice unless the wall be entirely submerged, and that using this maximum the factor of safety should be unity. With this he was in entire agreement and believed that by so doing members should have an ample factor of safety for the normal case. He thought the author could have drawn attention to the fact that this applies only to the body of the wall where we have materials whose crushing strength is far above any load that they are likely to be called upon to bear, but where the size of the foundation is to be considered the governing factor is, in nearly all cases (except in a wall founded on solid rock), the bearing power of the soil, as when the thrust passes through the limits of the middle third of the base the maximum pressure is twice the average, and when it passes through the toe the maximum pressure is four times the average. What safe minimum should be taken for this rarely to be obtained maximum is, as the author says, dependent upon the breaking. Therefore its value and position can only be obtained by considerable experiment with all kinds of backing in every stage until we approach complete saturation. Until such experiments in sufficient numbers to admit of our working on the data obtained have been carried out, he could not see that we could do other than design our walls as we do to-day according to Rebhann construction, keeping our thrust within the limits of the middle third when dealing with materials that can carry no appreciable tension, and seeing that under no circumstances are our foundation pressures excessive. Where this has been done practically all walls have proved safe and such experiments as have been carried out have proved that the walls have not been unduly heavy.

Mr. H. Oldham said: On the question of the slope which was taken by such material as sand he urged the desirability of caution. It appeared to him very difficult to make an experiment in a small way in such a matter. They had to remember that when a retaining wall was put up it was not there to support the pressure which the sand might bring upon it to-morrow, but it was to stay there for all time. There was no doubt that it was an experience of any engineer who had had to deal with this material that he had noticed as perhaps the first action that sand would arch. They had all seen vertical faces of sand that would stand for some time. Later on a slip would occur. There would be movements for some weeks, finally bringing about the 1 to 1 slope which a previous speaker had referred to, but his personal experience was that that 1 to 1 slope was by no means the end. The effects of the weather and other conditions which were brought about by time undoubtedly would produce a very much flatter slope. What applied to sand applied more or less to other materials of less uniform texture. It all, to his mind, pointed to the fact that it would be very unwise to err in any way except on the side of caution in these matters.

Mr. Young said the subject was too intricate to lend itself to design by calculations alone. It appeared to him that this was one of the many engineering questions in which we had to call in the aid of experience; in fact, it appeared that a considerable number of engineering questions were still solvable only by experience. He would like to quote a kindred subject to the one under discussion. They had adopted a uniform slope for embankments from $1\frac{1}{2}$ to 1. It would be interesting to see what slope would be arrived at by calculation. He did not think the adoption of this slope as a standard had been in any way governed by calculation, but was entirely a matter of experience. In the same way the thrust of an earthen bank against a retaining wall might vary for quite a considerable degree during the twenty-four hours of the same day owing to a change in the moisture, etc. The case of pressure of water against a retaining wall was quite capable of solution mathematically. In that case the angle of slope is a horizontal line. It is rather an interesting fact that the less fluid the material the steeper the angle of slope and also the higher the centre of pressure.

Mr. F. W. Lawson said there was so much in the paper that one did not feel very much inclined to go through the whole thing in detail. He was rather inclined to think that the formula laid down by Mr. Tomlinson was revolutionary. As a matter of fact it was mostly based on experiments which to his mind were not at all conclusive. The question of the stability of a wall could not in any way be determined by laboratory experiments,

and that seemed to be very largely from what some of the arguments had been advanced. Coming to his own experience in regard to the sand, which seemed to be largely the factor that had been used in this matter, practical experience did not, to his mind, prove that the author's basis was really a sound one. It was assumed that sand had an arching effect and under certain conditions would arch. He did not think that could possibly be proved in anything like extensive experience. He was basing that on his own experience in sand of various natures. He did not think it was safe to assume that dry sand had any adhesion at all. The experience that he went on was this, that in tunnelling work in dry sand where the best of conditions held in excessive depths over the heading of the drive at the back of the laths that was almost impossible, and he had never known a case yet where arching could be noticed or it was safe to assume that it existed. Even in most careful work being done lines of settlement could be traced for various distances alongside the tunnels, and from his own experience that slope over which the settlement took place affected practically a 1 to 1 slope from the bottom of the tunnel to the surface. He had known that almost under any depth. The depths varied from 10 to 70 ft. and yet the same effect was noticed. This could be very easily traced under certain conditions where they had a hard artificial surface over the lines of various operations. In several instances they had had cases where there had been well-defined and settled footpaths with asphalt surface immediately adjoining extensive tunnelling and from very careful observations it had been shown that cracks could be noticed almost invariably on the slope of 1 to 1. This to his mind showed that the fallacy of experimenting with sand under laboratory conditions was not practical; it could not hold because there were certain factors which proved that sand would not be stable under the conditions set out. It might be right to assume that sand in a combined box, such as the author stated had been experimented with, and well backed, had practically the same condition as they had in a moulding shop where sand did bridge. In actual conditions where other factors had to be considered, where it was subject to pressures outside the range of a laboratory experiment, sand did show an inclination to settle down, and he did not think the theory that they could rely on sand arching to any extent was one that could be said to have been established. They should be very careful before they broke away from the existing methods of calculation and in any way reduce the thickness of their retaining walls. They did not know, unless very bad construction had been proved, of any retaining wall having given way that had been built on the accepted formula; on the other hand, there were many instances where experimental walls had been put up and failures had taken place. They could put it down as a certainty that once they

departed from recognised formulæ they did not know what was going to happen. On the other hand, if they stuck to accepted methods they was some degree of certainty which, in engineering work, was so necessary and so desirable. He certainly thought the tendency to reduce was not warranted, especially when it was based, to his mind, on experiments which were not at all conclusive, and in his own experience not borne out by practical observation.

Mr. Tomlinson, in replying, said it was recognised that practical rules for use in design were not necessarily sound because the structures resulting therefrom satisfactorily fulfil their functions. The proper design of engineering structures required that the maximum effective conditions should be considered, and the fact that the structure stood was no sign of its proper design. The aim should be to try and eliminate in a rational manner as many uncertainties as possible, and not to be merely content in erecting something which will stand. Now, every physical law could be represented in the form of a mathematical equation. Any difficulty that may arise was really due to the complicated nature of the phenomena alone. In consequence it was generally found expedient to introduce simplifying assumptions into the mathematical analysis. (Thus, Rankine assumed, amongst other things, that the filling consisted of an incompressible granular mass, *without* cohesion.) These fundamental assumptions, the so-called premises employed in deducing a formula, must be clearly remembered. However correct the reasoning may have been, any limitations introduced as premises must, of necessity, reappear in the conclusions. The resulting formula can in consequence only be applied to data which satisfy the limiting conditions. Again, even when the comparison between the observed and calculated results is considered satisfactory the errors of observation may quite obscure the imperfections of the formula based on incomplete or simplified premises. This is most important when dealing with actual earth thrusts. (Prof. Ketchum* says the difficulty in measuring the exact pressures due to influence of cohesion and the movements of the filling are so great that experiments upon retaining walls have so far been of little value, and give no promise for the future.) The only safeguard is to compare the deductions of mathematics with observation and experiment, "for the very simple reason that they are only deductions, and the premises from which they are made may be inaccurate or incomplete." All this may be summed up by saying that it is impossible to get more out of the mathematical mill than is put in. The old theories of Coulomb and Rankine exemplify, in a forceable manner, the perils which attend the indiscriminate application of mathematical formulæ.

* The Design of Walls, Bins and Grain Elevators, p. 131.

These theories are still in use, although long ago the late Sir B. Baker, and other practical authorities, showed that the results obtained by those theories, even in favorable cases, greatly disagreed with actual results. The reason for this discrepancy is really obvious, and should be expected, for the premises—the peculiar kind of backing, etc.—have been overlooked. However, curiously, the general attitude in the past has undoubtedly been to assume that Rankine and Coulomb were correct and that practical conditions must be shown to agree with them. It is here contended that the natural conditions are fixed and that an endeavor should be made to fit a " theory " to them. Again, as seen from the paper, it has been taken for granted by almost all the " authorities " that the effect of an actual cohesive earth backing was similar to that of Rankine's uncohesive backing except that, in the former case, the value of the resultant would be smaller. But, as seen from this paper and other evidences everywhere, this assumption is not justified even when dealing with ordinary sand or earths. The following is an interesting abstract from an article by Mr. A. A. Steel* describing some experiments, on a larger scale than usual, on earth pressures :— " The diagram . . . . gives the results of the experiments with damp earth. It will be seen that the pressure against the upper measuring board increases much more rapidly than that against the lower one. For this reason the series was discontinued shortly after the upper balances indicated a greater pressure than the lower ones. It was supposed that this was due to the earth clinging to the sides of the pit . . . . and not settling freely. To avoid this the cohesion was destroyed by spreading the earth upon an asphalt pavement. Here . . . . it was completely dried. The experiments were repeated with this dry earth, but again the pressure on the lower boards was less. . . . . The experiments were then discontinued." Here we have a striking example of being governed by precedent. The apparatus was designed to accord with Coulomb's and Rankine's theory, and since the results were inconsistent with this theory they were unacceptable. As a matter of fact here is a perfect example of the " arching " of both loose and ordinary consolidated earth. Again Prof. Rankine developed formulæ merely for the two special cases of a vertical wall with firstly a horizontal surcharge and secondly with a surcharge sloping up from top of wall. In both of these special cases the resultant thrust on the wall is parallel to the upper surface of the backing and almost all writers have erroneously assumed that, in general, in Rankine's solution, the resultant thrust is always parallel to the top surface. What has evidently been forgotten for many years is that in calculating the thrust by the " ellipse of stress " amongst other things, there cannot be an active upward force or stress. The peculiarity here is

* Engineering News, vol. xlii, p. 261.

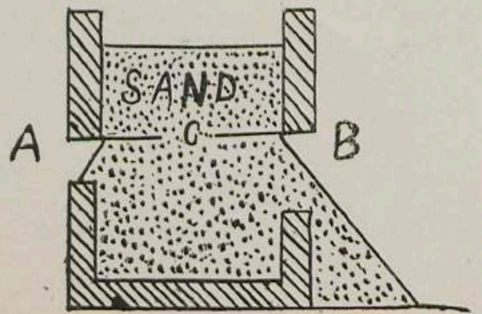
that the so-called Rankine general formula is not Rankine's at all, and moreover is incorrect in certain cases, but it must have been "faithfully" used many, many times. It is perhaps well also to point out again that Coulomb never pretended that his formula was correct when applied to practical cases. Further to reconcile these theories with practice it is apparently necessary to introduce and take friction at the back of the wall into account, and so Rebhann's construction may be used in actual design. The author, about five years ago, ascertained from a large number of the better known English firms or specialists in ferro-concrete and other retaining walls whether friction at the back of the wall was taken into account or considered in the design. The answer was almost invariably in the negative, although it was generally recognised that there was friction and that it would increase the factor of safety. It appears in obtaining the cross section of a retaining wall that the common practice is to obtain its dimensions by some empirical rule, such as thickness equals from two-fifths to three-fifths the height. This attitude, it is believed, is due to lack of confidence in the existing theories based on Rankine and Coulomb. It is justified by experience. So that inasmuch as something must be guessed at, why not guess at the size of the wall in the first place? Afterwards, so as to look learned, a "theory"—which, to a certain extent, is a method of answering or rather preventing awkward questions being asked—is used: generally Rankine's or Coulomb's constructions—with adjustments—are applied. After actual experience, the average designer realizes that the premises, that the conditions which have to be fulfilled before the theories are applicable, are not those generally found in practice even when the worst conditions for design are assumed (no cohesion), and so does not use them for cases for which they were never intended. Notice also that Rebhann's construction is not often or generally used. From the above it is contended that the objection raised that the paper is up against authority is not justified; and, further, that the attitude very often assumed that Rankine's and Coulomb's results hold good with actual earths, is not justified logically. The author agrees with Mr. Oldham, the substance of the remarks being contained in the early portion of the paper. As Mr. Kerslake points out, in actually designing a wall, after obtaining the resultant between the earth thrust and a proposed wall section, the tendency of the wall to slide bodily forward, and the intensity of the pressure on the foundation, must be considered. In this paper really only the first-mentioned above, namely the overturning of the wall, is considered. If the wall were designed by the new theory and the resultant passed through the toe of the wall then the greatest pressure on the foundation would be four times the average. If this resultant is likely to be obtained, then the wall must be thickened so that the resultant

will come within the mid third of the base or such rule. If, however, as is generally the case, this limit ($D = B$) thrust is never likely to occur then the average value of the cohesion will enable the resultant force to keep within the mid third of base so that the maximum pressure on the foundation will not exceed what is usually permitted—twice the average. With respect to Rebhann's construction, it should be remembered that it has been made, or rather arranged, to fit in with "practical walls," and so must give reasonable results in ordinary cases. In reply to Mr. Young, the author maintains that with rubble backing, friction at back of wall always exists. A vertical back was considered simply to reduce complications. The 1½ to 1 slope is simply a matter of experience. Since to calculate this by means of a formula —which is merely symbolised experience—necessitates a knowledge of this experience, in the first place, the calculated result would be 1½ to 1. The author prefers the formula :—

Thickness of wall, in ordinary material, $= {}^2/_5$ x height,

when there is no surcharge, this ration becoming ${}^3/_5$ when there is the maximum surcharge. Here the wall is assumed to have a vertical back and a battered face of, say, 1 to 8, the thickness of the wall being determined at the original surface ground level, while the height to be used is the height of the top of the proposed wall above the original ground level at the particular section. The author agrees with what Mr. Lawson says in the beginning of his criticism : "that he had not the time to digest the paper." A careful reading will justify this attitude. It appears also to be assumed that if it can be proved that sand does not arch, then cohesive materials—ordinary earths—do not arch. However, it is maintained that arching in ordinary earths, and in sand also, has been established. Only a few instances were given in the paper to illustrate this dominant property. That some kinds of earths do arch themselves is generally admitted. It is the admission of the fact as a general and accepted theory that seems to be objected to by many engineers. If it is true that "soft ground," or sand, does not arch itself, then it would be as impracticable, for instance, at a depth of 150 ft. to brace a narrow tunnel having a width of 20 ft. as a broad one having a width of 150 ft., and this, of coures, does not admit of argument. As is well known, the secret of good trenching, etc., is the avoidance of disturbing the "mass of earth," and, as pointed out in the paper, erroneous ideas of earth pressure may be produced from the fact that any bracing, etc., which admits of settlement develops in consequence greater or less pressure according to the degrees of settlement and consequent movement which is permitted to take place. The fact must not be lost sight of, namely, that bracing, etc., is primarily intended to hold the material in place at all times in a compact grip, and is not simply a barricade to prevent the occasional dropping of loose material. The ½ to 1

slope of the cracks in various earths, including sand, referred to in the paper were noticed when the bracing, etc., was sound and tightly put in. It is suggested that either the cracks noticed by Mr. Lawson were not the first cracks, or that the timbering was insufficiently tight or rigid enough. Thus at an early stage the cracks might take the ½ to 1 slope afterwards through movement, and time, becoming flatter and ultimately taking the 1 to 1 slope. It appears, however, that the latter suggestion above is the correct one, for it is emphasized by the apparent absence of arching when dealing with tunnelling. However, in any case, the 1 to 1 slope does not affect the new theory in any way. It is believed that in dealing with trenches and tunnels that insufficient consideration is given the subject of bracing, this latter being generally left to more or less intelligent foremen. It is thought that the subject is one requiring more engineering consideration than is generally given. Now suppose that a trench be dug in ordinary earth at the back of an existing retaining wall, so that the back of the wall is exposed, the sheeting and strutting being carefully and tightly put in. Now would the earth pressure with the strutting be the same as if an ordinary trench were being cut? Would the pressure at or near the bottom be the same as if it were 12 ft. or 40 ft. deep, say? Is it not reasonable to suppose that the action of the earth against the retaining wall is essentially the same as that of the strutting? Again, would not the strutting be essentially the same if the ground was opened by a tunnel from the bottom upwards as that used in ordinary cases of working from the surface downwards? All these questions must be answered in the affirmative. Suppose the backing material to be sand, with little cohesion: if a hole be cut in the side of the trench, the grains of sand will flow out until the opening is blocked up by the outflowing grains. There is absolutely no tendency for the grains to spout up as in the case of a fluid. If a vessel, as in sketch, be filled with fine dry sand, and openings be made in the sides, then, as shown at *A*, the sand will not flow out unless the height of the opening exceeds two-thirds



the thickness of the wall; but if, as at *B*, a larger opening be made, the sand will flow and pile up until its angle of slope reaches the top of the opening, and then no more will flow out. If the ordinary Rankine theory were correct, and the backing material is fairly similar to that postulated in this theory, then the pressure at *C* should be fairly great; however, actually the pressure appears to be very small indeed. Again, if sand be allowed to flow from an opening it flows at a constant rate, which is independent of the head, that is height of sand above the opening, depending solely on the size of the orifice itself. All this shows that the ordinary Rankine or "fluid" theories do not apply in practice even with sand, and more so with ordinary earths—arching action alone will explain the above phenomena. The actual law of pressure of grain and similar material on bin walls and bottoms is entirely different from the well-known "Rankine and Coulomb" law. Yet dry wheat and corn come very nearly filling the definitions of a granular mass assumed by these theorists, although the limit imposed by the walls prevents these formulæ being directly applicable. Experiments prove conclusively that grain arches, the pressure of moving grain only being slightly greater than when at rest. Grain bins designed by the fluid (Rankine) theory are in many cases unsafe, many steel bins designed according to this theory having failed by crippling the side plates. It will be seen that "arching" is not built up on a single simple laboratory experiment; the experiment, in fact, was called a *minor* experiment. It was merely to illustrate, in a homely way, the arching principle, and to show why it had not been discovered in the laboratory before. Only vertical arching has been considered, but horizontal arching is also important; thus it is always "recognised" in shaft driving. The author fails to see where any indication was given as to proposing reducing the thickness of retaining walls. Actually the opposite, namely, a widening, is the tendency, the arching theory allowing more scope in this direction, enabling the wall to be designed for any condition of the backing. Since reading the paper, the author's attention has been drawn to an observation by Prof. Ketchem, before referred to, namely, "that a *rational* theory for the design of retaining walls should be based on the laws of semi fluids, which can best be obtained by experiments made upon wheat, sand, etc., in bins." In other words, *arching* must be considered. It is intended shortly to attempt to determine the stress distribution by an optical method based on the action of polarized light.

CONSIDERATIONS ON THE ECONOMICAL DESIGN OF POWER PLANT.

(By Astley C. Cooper.)

There is probably no subject so much open to discussion the world over as that of power generation. Its economical production affects most branches of our profession, and should be of absorbing interest to those connected with engineering work in Australia. Upon the cost of power depends a great deal of the indsutrial life of a country. It is certainly only one factor in the cost of production, but one that is of great importance, and it will therefore be interesting to consider the trend of ideas as regards power plant here at the present time with a view to examining whether economy is attained.

Power users are somewhat apt to be prejudiced in determining the type of plant to instal, and select it, at times, it would seem, on the slenderest of evidence as to its value under given circumstances. In many of the cases I have come into touch with the proposals have been for alterations or additions to existing power plant and very great savings would have been made in nearly all had matters been placed in the hands of independent engineers, to prepare plans, specifications, and call for tenders and supervise erection, etc. This course would have eliminated all guess work in selecting the tender to be accepted and at the same time assured the right type being called for. Many questions besides technical ones come into consideration and there are always several possible schemes for any given case. The true engineering point of view is which pays best, and no one is more qualified to answer this question than the consulting engineer.

Technically the great problem with the production of power here is steam *versus* internal combustion engines. There seems to be a decided tendency towards the latter in some quarters—whether wisely or not.

The first question to settle before deciding upon the type of power generator should be its life—or rather the length of time the plant wi'l be sufficient for the work in hand, as permanency is a great factor in determining the allowable expenditure. In this State, which should be developing much faster than it is now, too long a time should not be allowed for recouping the outlay. Every enterprise should be in a position to consider scrapping its plant once in ten years in favor of one either more efficient or larger. This necessarily means a large depreciation and obsolesence fund.

Therefore the capital cost (in conjunction naturally with operating cost) should be the subject of very minute analysis. There should not be any stinting the cost of preparation of plans and estimates, or haphazard methods of deciding upon the type. Each possible method of working should be dealt with fairly and fully.

This is especially necessary when taking its useful life in conjunction with economy to be effected. In commercial enterprise it should also be carefully considered as to whether it is not advisable to cut capital expenditure to bedrock even at the cost of a large loss in efficiency, or economy, rather. For example, it is possible that an extra £1,000 or so might make a saving of 15% in working; at the same time that £1,000 might be the means of earning 30% if retained as working capital. Thus cases occur where economy *per se* should not be aimed at, but the cheapest type of plant selected; not necessarily the cheapest of a given type, as this may be very false economy by causing stoppage, breakdowns, etc.

Where a plant is so situated that it recoups the difference in outlay in a year or so, naturally a heavy capital expenditure is quite legitimate. This can only occur where there are some special local advantages for fuel and water, the source of which should receive due consideration, regarding cost and quality, although this point frequently seems to be rather neglected.

Steam *versus* internal combustion engines resolves itself here into steam *versus* producer gas. We have to dismiss such situations as occur in other countries, which have supplies of natural gas, blast furnace gas, or cheap oil supplies, or, again, a cheap central gas supply. The two former are practically very special cases. With regard to oil, it is entirely out of the question until such time as it is discovered in Australia except in the case of very small and isolated plants operating with a very low annual load factor. Roughly, it pays to put in a producer with a 5 or 6 H.P. engine if working more than half the year at its full load.

Central gas supply may hold out good prospects, as much could be done to cheapen the supply. It is now no longer necessary to supply an illuminating gas, as all such lighting is done by the aid of incandescent mantles; thus for lighting, heating and power work a gas lower in value and supplied at a higher pressure would have many advantages, the chief of which would be low cost.

So we have to rely solely on producer gas as the medium for power generation with internal combustion engines. They are only in competition with steam in certain classes of work

and within certain limits. As regards work, they compete for the generation of electricity, pumping, and direct driving of machines. Air compressing and winding, except in very small plants and work requiring variable speeds, is solely done by steam.

In large units also steam holds undisputed sway, and must do so for a very long time. It may safely be said that the uppermost limit of size for gas here is a thousand horse-power, but it will not be necessary for such a large plant to be dealt with. Also it is unnecessary to consider small powers, as the gas engine holds almost complete supremacy. Only the doubtful or intermediate position has to be therefore considered. I am fixing arbitrarily the sizes at up to 15 B.H.P. oil engines, and from 15 to 75 B.H.P. gas engines, as seeming to be fairly payable propositions for the majority of cases. From 75 H.P. upwards are doubtful propositions.

A great deal of the success of the gas engine has undoubtedly been due to its comparison with inefficient and badly laid out steam plants, and not, as should have been the case with up-to-date practise, and a great deal of follow-the-leader I think is also responsible. One is very apt to slur over the work required to thoroughly examine each phase—when one knows the nearest neighbor has reduced working costs fifty per cent. by installing a certain type of plant.

Gas engines are very economical thermally, which probably accounts for the rosy glasses with which we view them. They are twice as economical in this respect, and therefore we are willing to pay up to three times as much for fuel for them.

With regard to gas engines, a point which must be very frequently overlooked is that for about two-thirds of the cost a steam plant is about as economical, and, taking reliability and cost of stoppages into account, the balance may easily be in favor of steam.

The main claims on which a plant should be selected are: Firstly and most important of all is reliability; secondly, simplicity; and thirdly, economy.

Reliability.—Gas power is certainly not more reliable than steam, and it is very much open to doubt if it can equal steam plant in this respect. My own experience tends to show that it cannot, and that a thoroughly qualified man should be in charge if good results are to be obtained.

Simplicity.—Simple it may be—when it is working correctly. Should it stop, then it becomes a most complicated piece of machinery. The fault is in most cases exceedingly difficult to

locate and can only be done by trial and error method, which is exceedingly tiring. However, given proper attention and in charge of qualified men, we can allow that it is comparable to steam, and proceed to examine the claim for economy.

ECONOMY.—This necessitates a consideration of—

1. Fuel, water and oil consumption.
2. Labor and attendance.
3. Repairs and upkeep.
4. Depreciation.
5. Capital charges.

For actual working results of large gas engines I take figures published in the Chamber of Mines *Journal* under dates of December, 1911, for an engine of 170 B.H.P., and June, 1912, for an engine of 200 B.H.P. I was personally interested in the installation of these engines, and one of 400 B.H.P., having secured the orders for the firm I was at the time representing on the Goldfields. In using these figures I do so only as excellent illustrations for our analysis of the relative economy of gas and steam. The figures are as follows :—

SONS OF GWALIA.—Maximum B.H.P. of engine 170, working costs for August, 1911, average I.H.P. 147, average B.H.P. 128, charcoal used per hour 124 lbs. at 69s per ton ; the water circulated per hour in engine 15.20 gals. and in scrubber 540 gals. that lost by evaporation being given as 90 gals. on the cooling tower and 9 gals. in the vaporiser, or a total of 99 gals. per hour, to which must be added the loss from the scrubber : thus the amount lost would be, say, one gallon per B.H.P. per hour. The costs were given as under :—

Labor	B.H.P.	.0804	@	£31 6s.	per month.
Fuel	,,	.357	@	£139	,,
Water	,,	.03	@	£11 14s.	,,
Repairs	,,	.08	@	£31 4s.	,,
Stores	,,	.0017	@	£6 12s.	,,

Making fair allowance for scrubber water, etc., lost, this would bring up the water by one-third or £15 12s. Evidently also some error has crept in to the store account, as the oil alone must be three times this amount, as will be seen from this next set of figures.

YOUANMI.—These are for a 200 max. B.H.P. engine for April, 1911. Average B.H.P. 147, charcoal per hour 147 lbs. at 59s. per ton ; water circulated per hour for engine 1,816 gals., and for scrubber 562 gals.; loss by evaporation on cooling tower

73 gals., and in vaporiser 17.6 gals. per hour. Again no allowance has been made for loss of scrubber water. The costs were given as follows :—

Labor	B.H.P.	.155	£69 16s. 10d.	per month.
Fuel	,,	.316	£141 10s.	,,
Water	,,	.032	£16 2s.	,,
Repairs	,,	.100	£48 13s. 6d	,,
Stores	,,	.087	£37 17s. 2d.	,,

Here the amount is given as 147 gallons for the consumption of lubricating oil for the month. Labor at 15s. per shift and the consumption of condensed make up water to over 16,000 gals. The figures are said to be a fair average for a monthly run and both engines had been running several months before testing. Particularly the repair costs should be noted.

Now, as rapid as has been the development of the gas engine within the last few years, that of steam practice has probably exceeded it. For small stationary work it is now no longer necessary to talk of steam consumption of 30 to 50 lbs. per H.P. per hour. Tests show that 10 to 14 lbs. are easily obtainable in average practice.

Any average maker, for instance, will give the following guarantees with the Locomobile type of engine :—

30/60	H.P.	14	lbs. per	B H.P.
60/100	,,	13	,,	,,
100/150	,,	12.5	,,	,,
130/300	,,	12	,,	,,
300/450	,,	11.5	,,	,,

Those figures are by no means the best obtainable with the type mentioned. Thus for the Wolf engine, the pioneer of them, I have noted the following from results published from time to time for compound condensing engines :—100 H.P., .89 lbs. ; 138 H.P., .79 lbs. of coal per B.H.P. Assuming the high evaporation of 12 lbs. of water per lb. of fuel, the steam consumption would be for the 138 H.P. 8.14 lbs., 100 H.P. 9.15 lbs.

The well-known Bellis engines of 300 H.P. triple expansion have been tested down to 10¾ lbs. per H.P. per hour, using superheated steam at 300 F. But it is not necessary to go to such refinements as triple expansion and 300 F. superheat, or high speed even.

Kent, in describing the Lentz engine, takes the following from the *Engineer* of July 10th, 1908 :—Cyls. 14½ x 24¾ x 27½, 366 I.H.P., steam 170 lbs., vacuum 26″, speed 167 r.p.m., steam

consumption 12.3 per I.H.P. Same engine and conditions, but with steam superheated 150 F. (which is fairly moderate), consumption 10.4 lbs. per I.H.P. On this type of engine I read of a test some months ago on a simple engine of 160 H.P., non-condensing. The consumption was 19 lbs. per H.P. per hour, which, if corrected for super heat and condensing, would give a result in line with those just mentioned. The engine had been at work 12 months, and was tested under working conditions. It will therefore be seen that it is not necessary to have even compound engines to give economical results.

We now come to a different type altogether, which is known as the straight or Uniflow engines. These are two well-known designs, viz., the Stumpf and the Kerchove engines. The working principle and general design is probably well known, so we will only consider working results. After the first experimental engines were built a 500 H.P. engine was built and tested in Germany in February, 1909, with these results:—503 I.H.P., B.H.P. 465, steam 10.1 on I.H.P., pressure 169 lbs., temperature 581 F., r.p.m. 121, vacuum 26.4 inches absolute.

Another engine built in Switzerland: 300 H.P., single cyl. 23.5 x 31.5, 155 r.p.m., steam pressure 130, temperature 617, 8.5 lbs. per I.H.P., 13.7 per K.W. Same engine and conditions except no superheat, 10.6 per I.H.P. Again, an engine built in Holland: cyl. 12.6 x 19.8 stroke, 200 r.p.m., 80 H.P., pressure 149, temperature 662, steam 9.7 per I.H.P.; and an engine built in Denmark: cyl. 17.8 x 23.5, 185 r.p.m., steam 138 lbs. temperature 662, consumption 9.5 per I.H.P. These engines also have an extraordinary flat consumption curve, therefore at low loads the amount of steam required per H.P. per hour is little more than at full load. At the close of 1910 there was over half a million H.P. of these engines built. The Kerchove engines if anything are slightly above the figures given above.

It would seem from the figures just quoted that we must estimate steam consumption for engines from, say, 80 H.P. upwards at from 10 to 12 lbs. of steam per B.H.P. per hour (in any case under 14 lbs.), and at these rates it is not necessary to go to the gas engine for economy as far as fuel is concerned.

Before leaving steam consumption it might be mentioned that with turbines results are somewhat higher, say from 14 to 20 lbs. of steam per H.P. in the small sizes we are dealing with. Their economy for competition with gas engines need not be based on fuel consumption but more on oil and upkeep costs, saving in space and weight—chief of all, capital cost.

Turning now to the boiler house that has so assisted the gas producer to close it down. Very great economies are possible, but one almost looks in vain for any sign of proper management

or knowledge of up-to-date practice in small installations. The boiler house is the steam factory, using water, fuel and air as its raw materials, and labor and accurate records of costs, outputs, etc., should be kept from day to day. Valuable heat is literally thrown away in 90% of our steam factories to-day because of want of attention. There is no part of a power plant where waste is so liable or where greater savings can be made with small expenditure.

Of all the ready means to economy feed heating and utilisation of exhaust steam seem to be the most neglected. When it is considered that steam for auxiliaries costs practically nothing when exhaust steam heaters of the open type are in use, it will be seen what large savings can be made in the cost of working them. Again, very short calculations show that exhaust used in this way is twice as efficient as when used in an exhaust steam turbine. In conjunction with live steam heaters they are even preferable to flue economisers, as they are easier to clean and more compact, and are efficient feed purifiers. This will be seen from the fact that at 220° F. 50% of scale-forming matter is deposited and at about 290° practically the whole is thrown down. Speaking of the prevention of scale, it is worthy of note that later experimenters put down the loss at greater figures than usually accepted ; thus scale 1-50th of an inch thick results in a loss from 8% to 9%, according to whether it is hard or soft.

Live steam heaters, as mentioned, would eliminate most if not all scale-forming matter, but they are also valuable from other points of view, even supposing the usually understood economy of 6 to 8% did not eventuate. They allow a small boiler to be used and provide a "Thermal" storage at or near boiler temperature for use in case of peak loads, etc. With a system such as this no boiler need be used as a feed heater or scale collector and thus result in being a much more efficient piece of apparatus.

One of the greatest sources of loss in connection with boilers is that of the heat in the flue gases, and in many cases economisers of the Green type are put in to recover a portion of this. The reduction of temperature cannot be carried to a very great extent, as the draft is dependent on the difference in tempreature between the inside and outside of the stack. I have come across instances in this country where economisers had frequently to be byepassed to enable steam to be kept up. Now chimney draft is exceedingly expensive both in capital and working costs.

The alternative is mechanical draft—either forced or induced —and the working cost of this is roughly one-eighth that of the chimney, thus resulting in a large saving of coal by enabling very much greater economiser surface to be used. But it goes further by enabling the use of pre-heated air to be supplied to

the furances and at the proper point to insure complete combustion, resulting in further large economies. In the only instance I know of in Western Australia it is said to result in a fuel saving of 8%. It should be possible to regain much more than this, as a large percentage of the whole of the heat in flue gases could be returned to the boiler. As an illustration of the value of this pre-heating air I am taking extracts of some English tests from a paper read before the Iron and Steel Institute in 1907, as follows:—

Lancashire Boiler, 8 ft. dia. by 23 ft. long.

	Draft.	
	Natural.	Induced.
Temp. feed	47	142
Steam press.	93	84
Coal per ft. of grate	25.8	30
Per cent. ash	7.08	6.2
Cal. Val.	14,000	13,000
Actual evaporation	6,724	10,180
Actual per lb. of coal	6.68	9.42
From and at 212	8.07	10.45
Efficiency	55 6	77

The figures for natural draft are the mean of firing tests in a prize stoking competition for avoidance of smoke, conducted by Mr. R. H. Radford, and therefore represent careful stoking. It will be noted that induced draft increased the capacity of the boiler nearly 50% and at the same time effected a saving of coal of over 25% after deducting power required for fan and using inferior fuel.

Water Tube Boiler, pressure 147 lbs.

Gases entering heater °F	533	606	626
" " fan °F.	410	475	480
Air entering grate °F.	271	300	308
Feed temperature °F.	76	80	81
Fuel per sq. ft. lb	25	35	40
Water per hr. lb	11,300	15,183	16,833
" pound coal lb	10.04	9.64	9.35
" from and at 212	11.93	11.42	11.06
Efficiency %	81.4	76.37	74.5

These were forcing tests and varied from 25 to 85% above the boiler rating. With mechanical draft much can be done towards smokeless draft by proper control of the air supply.

One other instance worthy of note is that of Steel, Peech and Tozer's works, where two Lancashire boilers, 7′ x 30′, had to be forced, with, of course, loss of efficiency; the evaporation was 5.88. These boilers were replaced with one boiler, 9′ x 30′, with heated air. This easily handled the load, the evaporation being 10.18, or an increase of over 73%.

It will thus be seen with proper design the capital cost will not be much increased if at all, owing to the savings possible in the size of boiler and smoke stack. I was almost tempted to suggest alterations to combustion arrangements and methods of firing, etc., of boilers for our Collie coal. However, that outlined will be sufficient at present.

Before proceeding, let us examine possible evaporations with, say, Collie coal of an average value of 10,500 B.T.U. per pound, deducting 1,000 B.T.U. to cover loss for evaporating moisture contained therein, etc. (at 12½% moisture the actual deduction would be, say, .150 B.T.U., however assuming 1,000). The available heat is 9,500 B.T.U. and the evaporation per lb. would be for boiler efficiencies of 75% and 80% as follows for steam at 150 lbs. :—

Feed Temp.	75% Eff.	80% Eff.
180	6.83	7.28
210	7.04	7.5
280	7.55	8.05
320	7.9	8.41
360	8.25	8.8

I maintain that 80% is quite reasonable, and in no case should a boiler be allowed to go on working under 75% without very careful inquiry into the reason for it, and it might be added that a higher efficiency than 80% ought to be aimed at.

Superheating requires no remarks, as it has been assumed throughout. A great deal might be done in existing installations by the addition of superheaters for very moderate degrees of superheat and efficient covering of steam pipes to reduce condensation losses both in pipes and cylinder.

Turning now to condensers, the first consideration will be the degree of vacuum, having regard to economy and cost of fuel. This point requires a good deal of figuring when designing a plant but need not be considered here as we are more concerned with the saving of water. Very much could be done if a type of evaporation plant were developed here as they are very economical in water especially and in power required for pumping, etc., and no cooling tower is necessary with them. The amount of water pumped would vary from about one gallon

at full to nil at light loads, the loss from evaporation amounting to about two-thirds of the weight of steam condensed at full loads. Then we have either jet or surface condensers. With the former, boiler water would be used for condensing purposes and any available source of water with the latter. Now assuming a vacuum of 27½ inches and water at 81° F., the amount required in circulation varies from 4.2 gallons with jet and 7 gallons with surface condensers, showing a large amount of power for pumping, and with ordinary cooling towers a large loss from evaporation. For this reason surface condensers will not be considered further.

In cooling towers as ordinarily constructed, I put the loss down at from 3 to 5%, though engineers in charge of large plants assure me that it is much less, and most put the loss down at 75% of the weight of steam condensed. This corresponds to .75%, which, as I have said, is much too low to my ideas. The calculation under given conditions is quite simple to obtain the theoretical loss. Again, we should turn to mechanical draft to dissipate the greater part of the heat and then resort to evaporation for final cooling. In this way the loss would be at or under .5% of the water circulated. The loss with evaporative condensers would be on a 12 lb. steam consumption .8 gallons per H.P. per hour, and with jet condensers and cooling as above 12 lbs. x 4.2 gallons x .5% or .25 gallons per H.P. It will be noted that both these figures are well below the water consumption of gas engines. The foregoing points to steam being as economical as gas as far as water and fuel are concerned.

With gas engines the very working fluid demands a greater supply of a high-class oil. Comparative figures are very difficult to arrive at, but at least with steam it is possible to recover a good deal of oil for re-use. Gravity or pressure oiling system can also be used, resulting in great economy. However, allowing for extra supplies, such as packing, etc., for steam plants, it is safe to say they will not exceed the gas engine in this respect.

Labor and attendance and upkeep and repairs in small plants are not usually separate except possibly in regard to expenditure on new parts. With local conditions the largest part of the savings is made in attendance. On small plants this can be cut down to very fine figures, the actual time spent, including monthly cleaning, does not exceed on an average two hours per day—that is, if the plant is in good order. Then again this amount of attendance is generally given by any available labor. This point of unqualified labor is probably the worst feature with gas engines and must result in heavy depreciation through neglect.

On larger plants, as the 170 and 200 H.P. engines previously mentioned, we observe that in one case half time is charged, notwithstanding the fact that the engine is placed in the main engine room and probably only accounts for a quarter of the H.P. installed there, and also that all special attention is given by the mine engineer, whose time is probably not charged. In the second case full time is charged, showing no saving over steam plant in this respect.

Turning to repairs and maintenance, the fair average monthly figures are £31 4s. and £48 13s 6d, respectively, and speak for themselves. As it would take a mighty poor steam plant to exceed them, it is difficult to guess at what the repair bill will be as the engines get old. It may be as well to add that they quite dispose of the "foolproof" claim.

Now to consider annual charges of interest and depreciation, whcih should be shown as a power charge in all plants. The amount to be allowed is, of course, a matter of policy. It was mentioned that ten years should not be exceeded. Personally, I think three to five years ample in the majority of cases, and for safety 50% should be written off in the first two years.

Should any development take palce at any time, resulting in a cheaper plant and more economical working, the result is a very sudden drop in value. I might instance the case at present of the down draft producer, which has already resulted in scrapping plants that have not been installed more than a few years.

Again consider the starting up of a central plant, such as is proposed for Perth. If current is sold at or under one penny per unit the result will be the immediate depreciation of all power plants in the metropolitan area by about 100%. To consider the effects of these annual charges we will roughly consider capital costs of the two types, and a particular case will be taken, viz., a 400 B.H.P. gas engine driving an electrical generator of 250 K.W. on the Goldfields. The capital cost of engine, generator, switchboard, gas plant, piping, foundations, erection, will be £8,000 The capital cost of a steam turbine generator, switchboard, boiler, feed-heater, economiser, feed pumps, condenser, smoke stack, and erection will be £4,000. These figures have been carefully estimated from actual results of similar work the author has had to deal with and are a fair average Lower costs could be obtained, and higher also. Fuel.—Wood is obtained at 15s. per ton; charcoal is obtained at 69s. per ton. Water is hard and costs 3s. 6d. per 1,000 gallons. For the gas plant the figures at 1 lb. of charcoal per B.H.P.,

and water at per H.P. rates as given previously are :—

Fuel cost	£360	0	0	per month
Water cost.....	28	16	0	,,
Total	£388	16	0	,,

For steam, allowing an evaporation of 3½ lbs. per lb. of wood, and that the turbine at full load takes 14 lbs. of water per B H.P; and none is saved then :—

Fuel cost	£315	0	0	per month.
Water cost........	56	10	0	,,
Total	£371	10	0	,,

or £17 in favor of steam.

Now oil cost is all in favor of the turbine, as it is only used in bearings, and it would be difficult to imagine more than £20 per month for upkeep, and it appears from the working results on the smaller engines that the gas engines will be double this. Now take depreciation at 10% and interest at 6%: the debit against the gas plant is 16% on £4,000, or £53 per month. Again, in most commercial plants a profit should be shown on the investment, and if we take this into account and also the fact that in mining it is usual to write off the plant in three years, another 16% to 20% on the difference in cost should be debited against the gas. The above figures are based on full time working at full load. Cut the annual load factor down and the investment becomes worse still. It is worthy of mention that the evaporation of 3½ lbs. per lb. of fuel is obtainable without feed heaters, etc., allowed for in the cost, and also the attention would be if anything under that of the gas engine.

It is only quite recently that it has been possible to use Collie coal with gas plants, and results are still very far from being good. Considering the relative costs on the Coast, the gas engine might show up a little better as regards fuel. Water would not be such a big consideration and the difference in capital costs would be less—somewhere about £750—but it would have to contend against a very low annual load factor in the majority of cases, and this would tell against it enormously. Accepting the competition with Collie coal and disregarding the poorer types, with careful selection of engine and attention to details of design as outlined, almost as good a case can be made for the steam engine of 100 H.P. It is manifestly impossible to deal with all parts of the plant in a short paper; however, one further point might be mentioned, *i.e.*, water supply. In most of the coastal districts it should be possible to obtain a sufficient supply of water for power purposes from tube wells.

These wells ought to be very cheaply put in, and pumping with an air lift the cost should not exceed from 1d. to 3d. per 1,000 gallons, pumping from one to 300 ft., say.

Before closing, a few words on gas producers may not be out of place. It is very doubtful whether the local design of down draft producers are likely to stay, anyway for large sizes, owing to the variation in the quality of gas. The trouble to my mind with these producers is that the amount of air admitted to the two zones cannot be balanced. It is obvious that there must be a fixed ratio of air entering either zone if the composition of the gas is to remain constant. The flow of air depends upon the resistance offered by the fuel column, which changes frequently and not proportionately in the two zones. Consequently the proportion of air entering at each zone is continually altering and it depends greatly on the load on the engine as to which receives most air. From this cause there is no certainty of action.

Prior to these producers being placed on the market, the author was dealing with some much larger gas propositions than any existing ones here, which included gas roasting of ores, firing of boilers as well as power. Naturally, the fuel problem called for very careful consideration and the type of producer also. After exhaustive examination of the down draft producer since that of Ebelmen, in 1841, to date, he considered as the most likely to prove successful the Westinghouse, which is one of the lines of Gorman's 1877 patent, or the Loomis Pettibome, arranged to work on wood. The propositions were delayed for further consideration of fuel and preparation of estimates and plans. The outcome of his work in this direction is the experimental gas firing, in use at Wiluna although he did not deal with this personally beyond its initial stage. The producers in favor here at present are particular adaptations of Thwaites' 1904 producer. Greater success should attend the development of Thwaites' 1885 producer, or of the Nehse 1879, with the special adaptation by Korting 1903 and Green 1910. D. Clark patented last year a producer that also holds out great promise. An adaptation is now being placed on the Australian market which may prove advantageous for wood fuel.

Down draft producers call for much more attention than those with up draft, and it is necessary for the attendant to be well versed in gas making and to be always adjusting the air supply and attending to the fuel, and even with small sizes must be continually on the job. For Collie coal this is very essential to keep a clean fire. We all know the clinging sort of ash this coal has and it is easily observed that with the fire, or rather the gas, zone extending from the top downwards, that the ash will

tend to accumulate there, and must be removed frequently by poking, etc. More frequent firing should also be necessary to keep as even a quality of gas as possible. For this reason the developments ot the types mentioned should prove of benefit here.

Discussion.

Mr. E. S. Hume said: I have very much pleasure in proposing a hearty vote of thanks to Mr. Cooper for the very able paper that he has delivered. In doing so there are a few points worthy of consideration by the members, viz., the short life that Mr. Cooper gives to the plant or plants generally, that is ten years' life when it should be scrapped, and again, in another part of the paper, where he says that 50 per cent. of the value of the plant should be written off the first year and that the whole of the plant would possibly have a life of three or four years. It appears to me that there are very few industries in Australia which can afford to act in that manner with their plants. Another point is that in connection with fuel. Possibly some figures may be given in connection with results that may be obtained from a gas producing plant using, say, Collie coal for a base, then charcoal taken from the various hardwoods that are available in the country, and also from the waste sawdust and shavings, and so forth, from the various mills, that possibly might be used, giving the amount of consumption per brake horsepower. Possibly a gas plant generally is not so reliable as a steam plant, and also that in many parts of the country there are not so many who know about what repairs are necessary to the gas as they might know concerning a steam plant and how to repair it. Therefore, in many places the steam plant appears to me to be more suitable for a young country. What is the life of a gas plant compared with a steam plant? How long might a gas plant be in use before the principal parts of it at least had to be scrapped? In giving the costs of the running of the plants it is not stated how old the plants were when the costs were obtained, as it appeared to me that the amount allowed for renewals was very small. In connection with the indicated horsepower of steam plants, it did not give the calorific value, for instance, of the coal or what class of coal was used. For instance, in one case it might mean that coal of a very high calorific value was used in one plant and it might be a different coal in another plant. It might be smalls, for example, which would have about half the value of the other or a third of the value, but it might not have the same evaporative efficiency. The author stated that the feed water heaters would prevent scale in boilers. Well, I would like to know to which feed heater the author referred, as I am looking out for such a feed water heater that would prevent any scale from being formed in the boilers. There was no mention

made in connection with the use of turbines with reference to the mixed pressure type that might be also compared with the other turbines and steam engines to which the author made reference. It was stated that if an opposition plant was installed in a town that the depreciation would amount to 100 per cent. I question that statement, too, very much in a young country such as this. The plant that is replaced by a larger or a more suitable plant might be sent up into the country districts and there made use of as economically, perhaps, as it had been the case when it was first installed. It was stated that by sinking a well you could get water for 1d. to 3d. per thousand gallons. The question is, if you have sunk the well and got the water, if it is going to be of any value at all as feed water for boiler purposes, or sometimes for any other purposes.

Mr. P. V. O'Brien: Mr. Cooper in his introductory remarks made some reference to some people being prejudiced one way or another. I confess I am a little prejudiced in favor of internal combustion engines for the interior of this country, and that may be only just because I have had more to do with them than steam. I do not agree with Mr. Hume in saying that steam is better for a new country—it may be on the coast, but not for the interior.

Mr. Dowson: I am sorry I did not have time to go through the paper as thoroughly as I would have liked. It is a paper that will come in for criticism. There are only a couple of points I wish to make. The first as regards feed water heaters. "Feed water heaters practically throw down all the scale producing matter in boiler feed water." I am sure boiler users would be very glad if they could find that heater. I do not think there is any feed water heater than can do it. I have had feed water heaters and also scale in boilers. Secondly, in the discussion that arose the question of load factor came out and one of the speakers questioned the utility of testing these machines, specially in a central electric power house, to the maximum, stating the load factor at a central station was also below the maximum. The load factor of a central station may be only 10 or 20 per cent., but that does not follow that the individual machine is not running at its maximum. The central power station should be so designed as far as possible to run the different sets at their maximum. That, of course, is a difficult matter, and therefore the testing of sets and giving the value of different engines, different dynamos, at their maximum output is, I think, quite legitimate. If a power station has an output at its big load of, say, 5,000 kilowatts that will drop down a great deal below that but the idea in building that station for, say, a load of 5,000 kilowatts would be to have machines so graded that you could

drop them off or put them on as you require them, and it would be necessary to split them up into a certain amount, according to what load was likely to be.

PROFESSOR WHITFELD: Those of us who have been on the goldfields recognise that Mr. Cooper has not given a fair go to the gas engine. I think he would have a difficulty in persuading a man out-back, where they would have feed water running about 400 grains of salts to the gallon, that he could run a steam plant with the same efficiency. As far as the cost goes, he says the cost of a steam plant is less than that of a gas plant. In putting in a 200 h.p. plant, in which I was interested, we did not find it so expensive as a steam plant. You have to allow a big margin on a steam plant. It would take you some weeks every year in cleaning boilers. You would have to put in a Cornish or Lancashire or some simple type of boiler. You cannot put in a water tube boiler because it won't stand. You probably have them inspected at least once a year, and you have to allow for repairs. To put in water softening appliances will cost a good deal of money and these things Mr. Cooper talks about, although they might be used in power stations of larger power, I think are out of question in a smaller power. For instance, superheaters and forced draught are impossible in a small plant. A man very often wants to get up steam from nothing. You have nothing to get up a forced draught with. If you get your boilers cold, unless you have a chimney I do not see how you are going to get a forced draught. The same with superheaters. It is quite a different matter running a small plant on the goldfields to what it is when you have a power house and matters of that kind. Several of Mr. Cooper's figures were not fair. The cost of power is, I think, greater in cases of steam plants. Take the case, say, of a 100 h.p. plant. You can get a gas engine for about £1,000, and putting it in and freight would be about another £500—that is £1,500. A boiler alone would cost about £1,000—a Cornish boiler. It would be probably out of commission three weeks in the year. Supposing it is a pumping plant—a town supply where you cannot stop for three weeks—you would have to allow extra boiler power for that time. You cannot put in condensers, cooling towers, feed water heaters, etc., for anything like £500, and in a case like that, out-back, without doubt the cost of a steam plant would be considerably more than that of a suction gas plant. I know a man close to us, they put in a steam plant before we put in our gas plant, and the four Cornish boilers cost £5,000. They used something like £400 worth of wood for one month. On the gas plant, running about 200 h.p., we used £150 worth of charcoal per month for power. If we had been developing the same power as they were we would have used about £300 worth, as against £450 worth of fuel.

They went into it seriously, so seriously that if the mine had had a longer life they were thinking of throwing out the steam plant and putting in a gas plant, and reckoned it would pay them. A good many details are not quite fair to the small gas plant. That does not say anything about a power plant getting up to about 1,000 h.p. Mr. Cooper talks about reliability. Undoubtedly the steam engine is more reliable than the gas engine, but at the some time the gas producer is a great deal more reliable than the steam boiler—that is my experience using bad water. I do not think there was anything very much more I desire to say. The instance he took of a central station: this was a larger station of 400 b.h.p. gas engine, 250 kilowatt generator. He took a case which was certainly in favor of the steam engine, because he took a steam turbine with generator, which is one of the most favorable conditions. In the case of a plant running slow mining machinery such as tailings, lifts and batteries—if he had been taking machinery of that description you cannot run it with a high speed engine; you must have something running fairly slowly. This would be more suited to a gas engine. The case of a generator and turbine is particularly favorable to the steam plant and not very favorable to the gas engine. At the same time I think we want to be very thankful to Mr. Cooper for these figures. He puts a very good case for the steam engine and one that makes us think hard, and that is the main thing we are here for.

Mr. Edmiston: Mr. Cooper's paper brings before our notice that experience has demonstrated that while as an efficient heat transformer the gas engine is probably all that is claimed for it, in combination with the suction type of gas generator it is not always as efficient apart from the producer as is sometimes claimed for it. In commercial types the gas engine itself has certain well-known inherent defects from which the steam engine is comparatively free, and these effects are more or less accentuated by defects in the gas producer, by the class of fuel used, or by both. The effect of this is that there has been a very great amount of failure and disappointment, much of which, as Mr. Cooper points out, could have been eliminated under proper advice. I intend only to deal with one or two points and those only which hold my greatest interest for the moment. Mr. Cooper has omitted to deal with one important factor of consideration in estimating the amount of capital that can be economically expended in procuring the greatest efficiency in power plant. I refer to the amount of work the plant is expected to perform in relation to the amount it could perform if fully employed. I find, however, that Mr. Cooper has dealt with the aspect of the subject as it affects capital expenditure, another factor which I had myself omitted and for which I am indebted to him. In further considering Mr. Cooper's paper, regarding the

necessity of depreciation of value, I am able to confirm my previous opinion that in adopting a ten years' life as an average for the purpose of his paper, he is liberal enough. While the extremes may be found to vary over a much longer period, it will be found to be more often over than under that period. In about twenty examples which I studied in 1909 for this purpose I find that the average life was very much less than ten years, and by eliminating the initial machinery which is invariably much too small to serve more than a year or two, and then calculating the average useful life, I find in nearly all cases it did not exceed nine years. No doubt the period will lengthen out as the industry grows and the country develops, but at the present time a workable allowance must be made for depreciation. Consideration of the problem must always be of interest and importance to the engineer, but as a purely commercial problem its importance is more or less modified by the nature of the industry and the prospects of development and other factors, but remember that in the vast majority of cases the useful life of machinery is determined by the growth and prosperity of the industry for which it is used, and since it is usually determined to be replaced because of that happy circumstance, the more frequently it has to be replaced the better. In dealing with the comparative simplicity of steam and gas plants, I think I succeeded, and on the spur of the moment, in demonstrating that Mr. Cooper's ideal plant might be a rather formidable affair or group of contrivances, but for, say, a plant of 100 h.p., that is about the size Mr. Cooper actually discussed, such an installation as I outlined would be out of the question and would, generally speaking, be applicable to a larger concern. I have come to the conclusion that he has made out a splendid case for the retention of the steam engine in a great many instances where it was formerly deemed advisable to adopt gas, and it is pretty certain, as many of us have long suspected, that there are many instances where gas has been adopted and where steam should never have been abandoned. There seems little doubt that the gas engine has come to stay, and when the producer has reached a reasonable condition of perfection, of which there is no reasonable doubt, it is destined to take a much larger share in the production of the world's industrial output. A selection of a suitable type of prime mover is a problem which is always more or less before the engineer, and Mr. Cooper's paper will, I feel sure, be of great value to the members of this Institution and especially to those members who frequently have the responsibility of dealing with a subject which may be outside their special department. That is all I wanted to say regarding the paper, but Mr. Dowson's remarks just allow me to add one or two more. In stating the previous evening that the question of the load factor of a plant would have some serious bearing on the question of the amount of money that could be economically

expended on a plant, I think I considered that that is a question which should be closely scrutinised. As a matter of fact, the load factor as it affects that question is somewhat different to what Mr. Dowson explains. If you installed economical plant for all those units of machinery which you instal, that is, if you installed economic plant for one unit, it argues that of course you would instal economic plant for all the other units, therefore you would have a very expensive plant indeed to work on a load factor of 15 or 20 per cent. With a plant which has a very large output, say, 100 per cent., as I pointed out, working up to its maximum, you have a very large amount of work for units to work over which you spread the annual cost of added capital, but say that was only 20 per cent., your power to reclaim or shall I say to compensate you for the extra cost becomes a very limited one.

Mr. Leslie: I think the author is right in recommending kerosene oil engines for the smaller power units in preference to a steam engine and boiler, when steam boiler is not required for other purposes. I would, however, raise the size of limit for the kerosene oil engine to 20 or even 25 h.p. instead of the 15 given by him, as being nearer the overlapping point with producer gas engine. In regard to gas engine and producers, I think the author makes much too low a limit at a range of 15 to 75 b.h.p. for these. I think it will be found in the great majority of cases the range to be considered would be from 20 to 250 h.p., and in some exceptional circumstances perhaps up to 1,000 h.p. I do not agree with the author that much of the success of the gas engine is largely due to badly laid out steam plants. They are more trouble to start, more difficult to adjust, and more costly to purchase than steam plants, and yet the number of installations is steadily increasing. I think their success is altogether due to the merits of the type for particular sets of circumstances. In regard to the two bills of working costs given by the author, I do not think that any conclusions can be safely based on these. I would have been glad if he had analysed these before putting them forward. For instance, the costs are given per month instead of per hour. Assuming the engines ran the same number of hours, as the repairs are separate, it requires some explanation why the labor on an engine developing 218 b.h.p. should be £31 6s. per month, and on another engine developing 147 b.h.p. it should be £69 16s. 10d. Further, I hardly agree with the author that the repair bills speak for themselves. I think they require some explanation. If the figures given for repairs are a fair monthly average, it astonishes me that the owners do not seek some other type of prime mover. The author mentions isolated instances of engines with low steam consumption, presumably for emulation. Some of the engines take a fair quantity of jacket steam in addition to the cylinder steam. He does not mention if the jacket steam is included. I am entirely

in accord with him in his remarks on down-draught producers, and agree that the consideration of the adoption of these should be approached with caution. The author makes reference to being associated with the installation of a gas producer plant for gas firing at Wiluna, but he does not tell us whether the gas was to be used for the roasting of ores or for boiler firing. If the latter, it would have been interesting to have had particulars, although personally I would not expect much in the way of evaporative efficiency from fuel used in that way.

Mr. Oldham: I noticed during the discussion that there was a chance of getting a little off the paper—of getting back to "gas *versus* steam." That is all very well, but there has been a good deal of discussion on that point. But Mr. Cooper's paper was on the question of small plants. I think one that is up to 100 h.p. or something of the sort. We, of course, have had our big plants in connection with the big production industries, gold mining, timber, and all that sort of thing, but I realise now that the farmer is becoming a very big factor in the progress of this State. With the increased price of wages it becomes ever more difficult to make both ends meet by employing manual labor; therefore, the farmer is asking for machinery to do practically all his work. Now there are further limitations. In some parts of the world a farmer is able to take 40,000 or 50,000 acres and work it in a big way. The land laws of this State prevent a man acquiirng from the Crown more than 2,000 acres, consequently the problem as far as we are concerned here is a question of dealing with a plant which can be bought and handled by a man with limited capital, such as would be required for the working of such small areas. I should be very glad indeed on the continuation of this discussion if we can get some talk upon the question of small plants. Compare the ordinary petrol plant with the steam plant. Of course there are very many things to be argued in favor of the oil plant. One speaker to-night has referred to the fact that the gas plant has a great many troubles, and another refers to the fact that the steam boiler has a great many troubles, but it seems to me very much like this: that while we do not expect a bull-pup to catch measles, he is very likely to get a dose of mange. My experience is that one plant is just as bad as the other under given conditions. He was sorry they had not been able to produce some more evidence on the matter, but, on consideration, it would appear that on such a debatable matter it would require more than a verbal discussion or even a written short discussion on such an important matter, because, as Mr. Leslie had pointed out, the difficulty was in arriving at the right point where the change should be made from one type of machine to the other. It appeared that the question was still shrouded with a certain amount of doubt. On the question of steam plant,

especially for a smaller type of work, in connection with those uses which Mr. Hume had spoken of—in connection with farming and in places where small powers were required, and where the conditions did not warrant the paying of large salaries for highly efficient drivers, there had come under his notice a particular type of steam engine which had been produced in the State and which was an adaptation—a very clever adaptation to his mind—of a particular type of engine which had been in use for a little while. The machine had been put together in the State, a good many of the parts imported, but, as it stood, it was a local production. The machine was built with a flash type boiler—simply a set of tubes which took the place of the ordinary boiler—something of the type of the circulating boiler. The steam was used at about 600 lbs. to the square inch, and the feed was automatic, the arrangement being that a small pump was run by the engine which maintained the water pressure in the cylinder at 600 lbs. There was a direct connection to the boiler with a retention valve. When steam was drawn off sufficiently to lower the pressure of the boiler, a little more water went into the tubes, which of course did not contain water, but were full of steam, which was superheated in the higher ranges of the coils, and as the water went in it immediately flashed into steam. It was used in a two-cylinder fast running engine, a trunk engine, encased, and it had forced lubrication throughout all the engine and smaller bearings. Members would, of course, understand that the lower coils of the boiler which were nearer the fire had not a very long life, but, as far as could be seen, any wear was due to the heat of the fire and not due to corrosion on the inside. The solids which were deposited were very easily blown out and there was apparently no scale whatever formed. This in itself was, of course, a great advantage in districts where there was difficulty in obtaining water. Altogether it seemed to him that the little machine was capable of considerable development, although, of course, there were points about it which would prevent its being used on a very large scale. He had simply mentioned that as a fact which might be of some interest in connection with the steam side of the proposition.

Mr. Cooper, before commencing the reply proper, raised one objection. He was not endeavoring, as some speakers believed, to oust the gas engine or to boost the steam. He had only asked for consideration to be given to both types so that a maximum economy could be obtained and to set a limit, if there was one, to the size beyond which it was not economical to go with regard to internal combustion engines in this country. Mr. Hume in his remarks raised the question of depreciation. The subject was more or less, he supposed, a matter of personal opinion, but Mr. Hume said that he had allowed altogether too short a life in putting it down at ten years. He thought the

point here was to be looked upon more from the rapid growth that all industries should be undergoing and that, as he pointed out in the paper, really the growth of the industry should be considerably greater than it had been during the last few years, in which case it would be necessary to wipe off the cost of the plant in the time stated. Mr. Hume also mentioned in connection with figures given for steam engines that calorific values and qualities of coal were not mentioned. He thought it was unnecessary to put in this, as the steam consumption would be the safest basis to go on, and they could allow for the evaporative efficiency of their own fuels. Both Mr. Hume and Mr. Dowson questioned him as regards feed water heaters and scale. In reply to Mr. Hume, the particular heaters referred to, as far as the live steam heaters were concerned, were the "Braithwaite" heater and the "Hopps" or "Hoops"—an American type. As regards the actual prevention of scale, it seemed to be pretty clear from reports on these two heaters that more or less the whole of the scale was deposited on the plates within. The scale-forming matter, as pointed out in the paper, pretty well 100 per cent. of it was insoluble at under 300° F., and as the steam temperature was, on an average, say 350°, it was practically only a time factor when the whole of the scale-forming matter would be deposited. With regard to the working results of these heaters, he saw some years ago some fairly exhaustive tests carried out in one of the large electricity stations at home—he had forgotten the name of it for the moment. They were carried out by Mr. Wilkinson, and it was proved conclusively that with a Braithwaite heater a temperature could be maintained within 10 or 15° of the steam temperature with the greatest of ease, and the heater itself was dealing with about 30,000 lbs. of steam —that was the capacity it was ultimately tested up to—he believed it was only put in for about 20,000 and the size of this heater was 2 ft. in diameter and 3 ft. 6 in. long. They could see it was not a very formidable piece of apparatus to attach to the boiler. The water was fed directly into the boiler by gravity, being dumped into the heater itself, and the heater was placed, say, about 12 in. to 18 in. above the boiler, and the feed then flowed in by gravity. In connection with those trials, Mr. Wilkinson designed a new type of live steam feed heater. He had not seen drawings or illustrations of the heater, but he believed it was used entirely on locomobile type engine mentioned in the paper. In his heater Mr. Wilkinson places it in the steam space of the boiler, the idea being to overcome any losses through radiation. Mr. Cooper believed it would be a very great advantage to place the heater outside and risk the radiation. With regard to the open heaters there were numerous types of these on the market, usually placed on the suction side of the pump and on which the feed could be raised to a temperature of well

on to boiling point—from 120 to 212°, and, under certain circumstances, a good deal higher. They would take pretty well the whole of the steam from the auxiliaries and there are a great many of these heaters at work in W..A, and he happened to know several members of the Institute had had experience in them, and he was sorry that they had not given a few remarks on them. Mr. O'Brien had not said much, but he mentioned that he had some Diessel engines working in the State (gas engines). at a low cost. He did not doubt this, but he did say he did not think the Diessel engine was a commercial proposition in the country. He had no actual figures, but from his point of view, just putting it roughly, the fuel oil would cost about 6d. per gallon at the very minimum, and at 6d. per gallon it would work out to about £6 5s. per ton on rails, say, Fremantle, and for goldfields work he should say that the freight would be from £4 to £5 per ton, making, say, £11 a ton for the fuel at Kalgoorlie, or where these engines were placed. The value of charcoal at the same position was £3 per ton, therefore there was a saving. One pound of charcoal would roughly be equal to half a pint of oil, which would make a saving of somewhere near, according to his ideas, £5 per ton on fuel. He thought the Deissel engine was one of the prettiest machines you could wish to look at, but he did not think it could compete with other types as regarded fuel in this country. Mr. Edmiston says that he demonstrated that Mr. Cooper's ideal plant might be rather a formidable affair or group of contrivances, say for 100 h.p.; such an installation as outlined would be out of the question. Mr. Cooper did not agree with Mr. Edmiston that it was such a terrible affair. For instance, they had the boiler, a steam pump for supplying water, drawing it through an open heater, probably the total space would be 10 ft. by 5 ft. high, and with no complications with the exception of one or two valves to adjust. Water was delivered directly into the live steam heater as mentioned previously, and thence into the boiler. As regards cleaning, either type of heater was well arranged, the scale was all collected, or nearly all, on plates which are taken out and cleaned with the greatest of ease. A superheater surely presented very little complication, and supposing a Co_2 recorder were attached, again this might be classed as only a type of recording gauge and required very little attention. If a Green's economiser were fitted, again they could hardly claim complication. There was a little more plant, but the complication did not seem to be very much to his mind. The live steam heater and the economiser seemed to be able to go together and each gave their own economy. With regard to the trials mentioned previously, he thought it was fairly conclusively demonstrated that there was an economiser of 288 tubes on the boiler, tested with the Braithwaite heater, and that raised the steam temperature to 240°, and the live steam heater

took it on to 340°, and there was an over-all economy due to the live steam heater, 10.18 per cent. To go on with this formidable affair—supposing induced draught or forced draught were put in, he did not think it was much more complication to have the draught under direct control by means of a fan than it was to have the variable draught under atmospheric conditions; in fact, he thought the man in charge of the plant would have a very much easier time. The same remark applied if a mechanical stoker were put in, and that practically covered the whole of the accessories mentioned in the paper, excepting he might mention draught gauges and a few other gauges, all of assistance in working the plant, but he should not say they added very greatly to complication. Turning to Professor Whitfeld's remarks: Professor Whitfeld said he had not given a fair "go" to the gas engine, and he would have very great difficulty in persuading a man out-back that he could run a steam plant with the same efficiency. Professor Whitfeld remarked that there they would have to deal with the feed water of from four to five hundred grains of solids per gallon—that water could not be used in a gas engine. It was infinitely worse in a gas engine than in a steam engine, said Mr. Cooper. If they could afford to condense water for a gas engine they could afford to condense it for steam, and he thought they would find that 16,000 gallons per month was sufficient with a condensing machine, provided they did not have to use more than 10 per cent. make-up, which might be on the fine side, but it was a fair estimate. 16,000 gallons per month would run a 150 h.p. condensing engine and that pretty well took in 20 lbs. of steam per h.p., which was not an efficient steam engine nowadays. As regarded the condenser, an evaporative condenser would have to be put in in this case, in which the density of the feed water would hardly matter. Again, Professor Whitfeld mentioned the cost of boilers. This point he would deal with a little later, but he could not agree with the statement that they had to put in a Cornish or Lancashire boiler. As far as he was able to judge, he thought the water tube boilers were quite satisfactory on the fields. He had seen them working under pretty well all conditions there and they seemed to be very much easier to clean and the repairs were no more than for a Cornish boiler. He also joined issue with the statement that superheaters and forced draught were impossible in small plants. He failed to see in plants of 100 h.p. why a super heater could not be put in. He believed that all makers of water tube boilers were quite willing to supply them, though he had not looked that point up. Professor Whitfeld also said that the instance that he took of a gas engine, that was the 400 h.p. engine, was certainly in favor of steam, because a steam turbine with a generator was one of the most favorable conditions for steam. He thought that remark fairly bore out the contention of the

paper that in many cases sufficient consideration was not given to both types of machine. It certainly was in favor of the steam, and if it showed out so well a steam engine should surely have been put in from a commercial point of view. With regard to slow running machinery as mentioned by the Professor, he pointed out numerous types of engine in the paper running down as low as 80 h.p., and the locomobile type at considerably lower, with consumption running from 12 to 14 lbs. per h.p. per hour. As he also pointed out in the paper, given conditions of evaporation, a steam consumption of about that compared very favorably on fuel consumption with a gas engine. With regard to Mr. Leslie's criticism, he certainly gave the pride of place to the oil engine up to 15 h.p., but he did not recommend it in preference to it, in fact he was going to mention some figures to show that it was not always so. Mr. Leslie said that the limit which he had placed at 15 h.p. for oil engines should be raised to 20 or 25 h.p. for oil engines and from 20 h.p. upwards for gas. If they took a 20 h.p. load, say, for pumping in the country the extra cost for a gas engine and producer would be somewhere about £150, and, taking depreciation and interest on the money and upkeep, say, a total of 20 per cent. annual charges on that extra £150 would be £30 per annum. Oil to the farmer in the majority of cases cost 1s. 3d. per gallon and charcoal 30s. per ton, roughly, thus the saving to them on an eight hours' run would be 15s. in favor of the gas engine. Therefore, if the engine was working forty days it was certainly rather a long period for pumping work, but give it forty days and the gas engine was then a payable proposition. That was, it paid interest and depreciation and upkeep on the plant; over forty days of course was all in favor of the gas. This illustrated the effect of the annual load factor on the type of plant to be employed; Now turning to steam for country work. Of that size many small steam engines can be obtained, running with a consumption not over 36 lbs. per h.p. per hour. Supposing they used 36 lbs. of steam per h.p. per hour and took a 20 h.p. load: if an evaporation was obtained of 3 lbs. per lb. of wood, this meant a consumption of 16 cwt. of wood per day. A boiler and engine would cost very little more than the oil engine, and with wood at 8s. ton, which he thought an ample allowance, and 10s. per day for wages, the cost would run out on a par with the oil engine—3d. difference. In this case one had to remember that probably not a penny of this was money out of pocket, as was the case in regard to oil. Mr. Leslie said that the range for gas engines should be from 20 to 250 and in some cases up to 1,000 h.p. He (Mr. Cooper) dare say there were many instances in which it would probably pay to put in 1,000 h.p. gas engine, but it would have to be somewhere pretty close to the coast, and the type would have to be gone into pretty closely; the freight alone

on this type of engine was apt to kill it when it got over a certain size. He was sorry he had not put in more figures in connection with that particular point. He intended to show, in connection with the load factor, the value of the plant, but he had not had time to do so. With regard to working costs of these engines which Mr. Leslie thought unfair—these costs had been published by engineers extremely favorable to gas; in fact, they were putting in larger plants than mentioned in the paper. It was their statement that the figures were a fair average for a monthly run. As regarded analysing the figures, the figures were given in the paper at per b.h.p. per hour, which Mr. Leslie asked for. They were at the side of the monthly figures, and considering those two figures, the repair costs on the b.h.p. per hour basis in the one case, Mr. Leslie said that he did not understand why there should be such a difference, between £30 and £60, in the repair costs. In one case it worked out at .08 of a penny per b.h.p. per hour, and in the second case .1 of a penny. In the first place one was a very much larger engine than the other, and repairs were likely to be more costly, especially in cylinders, and there was more handling, more trouble in getting parts adrift; and again, the relative position of the two plants was mentioned in the paper. There was 60 miles of cartage to Youanmi, which would probably make up the difference of .08 of a penny. To his mind the two results were strictly comparable and in repairs also. In connection with one more point raised: that of jacket steam. In the locomobile type of engine the steam jackets were connected directly to the steam space of the boiler and drained therein, so that all jacket steam used was practically accounted for in the fuel cost; and in regard to the uniflow type of engine, it was usual only to jacket the cylinder head in which the valves were placed, and this might be said to be a continuation of the steam pipe, as the steam went straight through the valve into the cylinder. They were working at an enormous superheat, so that there would be probably no condensation, or very little. Professor Whitfeld mentioned the cost of Cornish boilers out-back on the fields. He put the figures down at something like £1,000, and he had to have four of those boilers for certain work. If it is possible in one case at home with high velocity and exhaust fan to get such an abnormal evaporation and the heat transferred was 34,000 British thermal units per square foot against six in an ordinary boiler, would it not be possible for those out-back on the fields to put in one boiler in place of four with an induced draught plan and a high velocity of gases? He seemed to think from his study of the matter that it was a question which had been very much neglected here and it would bring the cost of steam down immensely below gas at the present time.

ELECTRICAL COMMUNICATION AND SAFETY APPLIANCES ON RAILWAYS.

(By Harold Dowson.)

It was my intention at first to read a paper on all electrical appliances on railways, but the subject would be too extensive to deal with in one paper, and so I must confine myself to-night to the telegraphic portion, so to speak, and will later if desired complete same by a paper on electric light and power. All modern railways use electricity very largely for communication, telegraphic, telephonic, block signalling of trains, and electric interlocking. A vast number of appliances to meet this demand have been invented and are in use, and in order not to be too discursive I propose to confine myself chiefly to the appliances in use on the Government Railways.

Briefly, the subject may be divided into five heads, as far as regards instruments, viz.: Telegraphs; Telephones; Apparatus for signalling on single lines—staff, tablet, etc.; Apparatus for double lines—block instruments, lock and block, automatic block; and apparatus for electric interlocking at stations and junctions.

Electric Lines.

As, however, all these require wires of some kind, it will be better first to glance over the construction of electric lines. A good many may think that the construction of telegraph and telephone lines is a very simple matter, and certainly some of the early examples of such construction in this country would not give one a very exalted idea of the engineering skill required, as the only thing that seemed necessary was to stick up a pole and hang wires on it anywhere and anyhow. The proper construction of a heavily wired telegraph line requires a good deal of skill, and a great attention to detail, to avoid annoying break-downs and constant repairs.

Telegraph Poles.

A telegraph pole is a highly composite structure, consisting generally of a pole with a number of wood cross-arms bolted to it in the centre of the arm, with insulators, in two pieces at least, bolted to these cross-arms, planted in any sort of soil and exposed to all sotrs of weather. The wires on it are always altering their tension through variations of temperature, offer a large surface to the wind, and unless the poles can be kept in a straight line, subject their supports to a very heavy stress. Under these circumstances it speaks volumes for the care and

attention that has been paid to perfecting the material they are constructed of, specially the wire and insulators, that we are able to keep wires 300 and 400 miles long working without interruption month after month.

Wooden Poles.

The poles used on Western Australian Railways are of wood, tubular iron, or old rails. The best timber I have so far found for poles is white gum, but, unfortunately, we cannot get any quantity of it, and we generally use jarrah. They vary in length from 20 ft. to 65 ft., and up to 35 ft. are sunk one-sixth of their length in the ground. In practice we find it very seldom any use, in ordinary soil, going down more than 6 ft. If the soil is bad we reinforce the pole with timber at the butt, or else strut with timber or stay with wire rope and tightening screws. Where very heavy stress is met with, as on a heavy curve, we bolt and brace two poles together, either in an H or A formation.

Poles are not treated in any way when first set, as they are always practically green, but after they have been set for a year or so they are opened out and tarred, and this is done yearly.

Iron Tubular Poles.

These consist of a cast iron base, with either a dished footplate bolted on the bottom, or a side plate about 18″ x 12″ on the side about a foot below ground. The top is a tube of mild steel, butt welded, and tapers according to length from about 4″ at bottom to 2″ at top. The two halves are joined by placing the top into the base for about 6 inches and driving down a tapered steel split ring, wedging the two together. In some cases the ring is screwed down. Brackets and cross-arms are clipped on round the pole. Lengths run from 18 ft. to 30 ft.

Rail Poles.

These are constructed of old rails spliced together to get the requisite length when necessary. A long pole would consist of three bottom pieces, two intermediate pieces, and one top piece. These fit into one another for about 2 ft. and are bolted right through. The web of the rail is bored to take the cross-arms. Lengths run from 18 ft. to 40 ft. All iron poles are kept painted when they are not galvanised.

All poles are numbered out from Perth.

Cross-arms.

Cross-arms are generally of karri, and carry 2, 4 or 6 wires. The finished scantling for 2 wires is 2″ x 2″, and for 4 and 6 wires, 3½″ x 2½″. They are kept painted.

Insulators.

There are two principal types of these used here, both English types, known as the Cordeau X straight shank and the J. The straight shank has a steel pin cemented into the porcelain, with an arm collar and nut. Permanent set with 784 lb. cantilever stress does not exceed ⅛″. The J bolts through the cross-arm from underneath and is made that shape to avoid undue leverage stress on the support, as they are used for terminating the wires on. Permanent set with 748 lb. cantilever stress does not exceed 1/16th″. The porcelain is the best that can be made, and, though highly glazed, does not depend on that solely for insulation.

Wires.

Galvanised iron and copper are the two metals chiefly employed, though phosphor bronze and a copper-clad steel wire are used for special cases, such as long spans, etc., where very high tensile strength is necessary.

Telegraph wires are known by their weight per mile, guage numbers being discarded The galvanised iron wire generally employed weighs 400 lb., and the copper wire 200 lb., per mile. The copper wire is hard drawn cold, which increases its tensile strength very much till it is practically equal to that of the iron. 400 lb. iron wire breaking strain is 1,260 lb., and that of the 200 lb. copper 650 lb. Resistance of the 600 lb. iron wire is 13 ohms., and 200 lb. copper 4.5 ohms. per mile. The wires are tied to the insulators with binding wire and pulled up so that they have a factor of safety of four at the lowest temperature they are likely to be subjected to. It requires considerable judgment to do this, and it is very difficult to prevent the linemen from pulling them up too tight, specially during hot weather. I have known several cases of wires tested showing 400 and 800 lb. stress and over in place of the maximum allowed, viz., 320 lb. On 4-chain spans, sag for 400 lb. iron wire at low winter temperature is about 2′ 6″, and for summer temperature 4′ 0″. For 200 lb. copper it is 2′ 2″ and 4′ 4″. Poles are set twenty to the mile, so that, for example, on our Geraldton-Nannine metallic circuit telephone line there are 6,200 poles, 12,400 insulators, 1,240 joints, and 57 tons of copper wire.

Telegraph Instruments.

These can be classed as visual, acoustic and writing. The instrument that has been used on railways probably more than any other, though never on these Railways, is the well-known single needle. It is a visual instrument. It is very simple and requires little attention and adjustment, but is not a fast instrument, about 10 words a minute being the usual rate of sending messages. It consists simply of a magnetic needle within a coil of wire with an outer indicating needle on a dial standing vertical.

With current in one direction the needle is moved to the left and in the other direction to the right. Combinations of these spell out a letter as \\/\ *F*, \\\\ *H*. Either two keys on one board, or a handle, fitted under the shelf below the dial of the instrument, is used for sending. If the left-hand key is depressed, or the handle moved to the left, the needle goes to the left. The telephone has replaced a large number of these, as they were very largely used in signal boxes for train work. Expert operators read this needle by sound, the difference between the sound of the needle on the left-hand pin and the right-hand pin being sufficient for a trained ear. Small gongs of different tones were sometimes employed, and Bright's bell utilised this system, but generally employed a relay, which was a disadvantage in that it spoilt the simplicity of the instrument.

Morse Instrument.

The Morse telegraph, with its familiar dot and dash characters, is the instrument on which the largest share of telegraph work the world over is done. The alphabet is the same as the single needle, the dot corresponding to the left deflection, and the dash to the right hand. Thus *F* is ..—. and *H* .... This instrument is worked simplex, duplex, and quadruplex.

Simplex System.

The simplex system sends one message at a time over one wire, employing two operators. The duplex system sends two messages over one wire, one from each end, employing four operators. The Quadruplex sends four messages at once over one wire, two from each end, employing eight operators.

Wheatstone System.

There is also the Wheatstone automatic system, sending up to 400 words a minute, in Morse code and various type printing telegraphs which print the messages direct on the tape. The Morse is used either as an acoustic or a writing system. The first is called the sounder, and the second the inkwriter. The sounder is most generally used, as it is, in common with all acoustic hand-operated telegraphs, by far the quickest. The inkwriter is only used when it is necessary to keep an actual record of what was sent for reference. As this is most desirable on a railway, our railway telegraphs are all, except Perth, equipped with inkwriters and a record is kept on the tape of each message.

There are two ways of working Simplex telegraphy. One is known as the "open circuit" and the other as the "closed circuit." In both systems all the instruments on one line are connected up in series so that any message is repeated at every station and any one can call up any other. In the "open circuit," however, each station has its own battery to work the whole line

with, and there is no current on the line except when a message is passing. To call a station the key is simply used to give the code call. In the "closed circuit," however, there is a large main battery at each head of the line, and current is kept on all the time. To call up, a switch is put over, breaking the circuit, and the code call given by depressing the key, which puts current on again. The open circuit employs a very large number of cells, as each station has to have a main battery, but current is not used when no messages are passing and it is free from the annoying breakdowns peculiar to the "closed circuit" system, caused by an operator accidentally or purposely forgetting to replace his switch. A huge number of cells are used for main batteries, but their place is being largely taken by motor generators. In common with the rest of Australia, we use the "closed circuit" system. We employ motor generators in place of main batteries, and are now introducing some modifications in the instruments to do away with the switch and thus remove from the operator the power of rendering the whole line inoperative, as too often happens.

The voltage used varies from 70 volts to 90 volts and current is 15 milliamperes, the lines being about 350 miles long and of 200 lb. copper wire. Owing to the length of the lines it is impossible to work direct, and relays have to be used. The main current passes through these relays and switches to a local battery of three cells, which operates the sounder or inkwriter. The relays used are the British P.O. type of standard relay, though a new one, known as the "Kamm" relay, in which the moving part is much lighter, is being now introduced.

The electrical details of sounder and inkwriter are practically the same. The inkwriter is simply a sounder with a clockwork register, and arrangemenst for printing on the tape. Long distance sounder consists of a relay and sounder coils. These latter are simply an electro magnet with an armature pivoted above same. Attached to the armature is a metal bar, which extends outwards and plays between two adjustable stops. The armature is held away from the coils by a spring, with the bar resting against the top stop, and when current passes it is attracted downwards and strikes the lower stop and thus makes a sound. The dots and dashes are read practically by the difference in interval between the sound of the top stop and the bottom one.

When attached to a clockwork register, the *modus operandi* is the same, but the opposite side of the armature carries a lever to which is attached the ink wheel. This is rotated by the clockwork, which also causes the tape to run through rollers just above the inkwheel. The downward motion of the armature gives an upward one to the inkwheel, presses it against the tape

and records the dots and dashes. Speed of tape is from 6 ft. to 8 ft. a minute. The inkwriter itself is generally read by sound the tape being only referred to in case the operator fails to catch a word or so. Thirty words a minute is considered good work; average, 15 to 20 words.

Only the simplex system is worked on Western Australian railways, and a full description of the duplex and quadruplex systems would take up too much space, as they are very complicated. It must suffice to point out that the duplex system is worked by so balancing the line resistance with the instruments at either end that each instrument is only affected by incoming currents and quite unaffected by those going out. In the case of the quadruplex the object is obtained by using two relays at each end, one of which is worked by change in direction of current irrespective of alteration in strength, and the other is worked by an increase in strength irrespective of direction. They are perfectly independent and actuate different sounders.

Telephones.

This instrument is probably the most familiar, best abused, and least understood instrument of any so far dealt with. I am not going to deal with exchange telephone working, as that is a three-volume book in itself, but shall simply deal with the telephone as an instrument and as used for long distance trunk and party lines.

The telephone as first invented is what is now known as the receiver. It can be and was used for some time as a transmitter, but it was the invention of the microphone that made it a commercial success. The telephone itself, or receiver, consists of a permanent magnet, round one end or both ends of which are wound a coil or coils of wire. Clamped directly in front of this, but not quite touching, is a disc of soft iron, held firmly all round the edge, but free to vibrate from the centre outwards. The microphone may consist of almost anything, as one or a number of unstable electrical contacts constitute a microphone. A very fair microphone may be made of three wire nails. Fasten two wire nails down on a board parallel to one another and an inch or so apart. Connect the wires from a receiver and battery, one to each nail, and lay the third nail across the other two, and complete the circuit, and the microphone is made. A complete telephone without calling arrangements consists of a microphone as transmitter, a receiver, an inductive coil, and a battery of from one to three cells.

Transmitters nearly all consist of carbon. Carbon not only has the property of being able to make a large number of unstable contacts in the form of granules, but its resistance can be varied by applying or reducing pressure on it. A transmitter consists

of a diaphragm clamped firmly round the edge but free to vibrate in the centre. Resting against this diaphragm is a small quantity of carbon granules carefully freed from dust, and as nearly as possible graded to the same size.

The action is as follows:—When anyone speaks into the transmitter the sound waves infringe upon the diaphragm, and, owing to its elasticity, give it a piston-like motion, the number of strokes varying according to the tone, and the amplitude to the loudness of the voice. The transmitter is connected through the primary of an induction coil to a battery. Owing to the motion of the diaphragm the electrical resistance of the carbon granules is altered, causing a pulsating current to flow. This is transformed by the secondary coil to an alternating current. This alternating current flows through the line and receiver and alternately weakens and strengthens the permanent magnet in same. This acts by magnetism on the soft tin disc and imparts a vibratory motion to same in unison with the currents, and by that vibrating motion given at the same sound waves as the voice at the other end. When the independence or capacity, or both combined, of the circuit are too high, the electrical waves become so attenuated or flattened out that speech is not practicable.

Calling up is done by a magneto generator. A coil of wire wound on a wire core is revolved by means of a handle between the poles of powerful permanent magnets, and gives rise to *AC* currents, which ring a polarised bell with two gongs. When two or more instruments are on a line, called a party line, it is necessary to have a code call for each. We use the Morse code lug rings and shut rings, and each station has a distinguishing letter. On our long lines the generators have six magnets and give over 100 volts and ½ ampere. Telephones are not joined up in series, as telegraphs, generally, but are in parallel, like the lamps on an electric light circuit.

Owing to the extreme sensitiveness of the telephone, it is a great eavesdropper, and the lines have to be metallic circuit and most carefully balanced. We have one single wire line between Southern Cross and Kalgoorlie, which so far has baffled all endeavors to provide a working telephone service on, as the noise from foreign currents drowns all speech.

Our longest circuit is between Geraldton and Nannine, 310 miles, with fourteen instruments on it. We can ring up and speak with ease. The telephone is very largely used for train working and here we employ it largely for message work. It labors, however, under the disadvantages that it leaves no record, that it requires two wires, and that it can be used by anyone. It consequently is used by anyone and everyone, and no training is considered necessary for a telephone operator, with the result that messages get a good deal mutilated.

Apparatus for Working Trains on Single Lines.

In the early days of trains, when they were few and far between, they were simply sent out and the driver kept a look-out. Then a time interval was given, and later they were telegraphed forward. It was soon recognised, however, that there should be some co-operation between the two stations of a section, and then the train staff was brought in. This staff was the key of the road between two stations, and drivers were not allowed to proceed unless they carried the staff. Each section had its own staff, which was taken by the driver at one end and delivered up at the other. The difficulty of dealing with trains following one another soon became apparent, as if the first train took the staff the next one had to wait till it was brought back. The staff and ticket were then brought in. In this system the staff and ticket are kept in a box of which the staff forms the lock. If the staff is in, the box can be unlocked and a ticket taken out. If the staff is out the box is locked and the ticket cannot be got. If two trains are following, the officer at the station unlocks the box, takes out a ticket, shows the staff to the driver, and hands him the ticket to proceed. The staff can then be used for the next train. This is still in use on many lines, but is provocative of many delays, especially to special trains, as the staff always appears to be at the wrong end of the section.

Staff and Tablet Instrument.

To obviate this, the tablet instrument and the staff instrument, both electric, were invented. The principle of both is the same and as we only use the staff I propose to deal with that only. The construction of the staff instrument provides that a staff cannot be obtained except through the use of the battery at the distant end of the section, and when once a staff is taken out another cannot be obtained till it is replaced in one or other of the instruments.

Let *AB* be a section and *A* and *B* the stations at either end. If *A* has to send a train forward and all is in order, he calls up *B* and asks by code for a staff. *B* replies and depresses his key, sending a current to *A*. *A* turns his local switch and lifts out a staff and signals to *B* that he has got it. The train can then proceed. No other staff can now be obtained at either *A* or *B* till the one taken out is replaced at either *A* or *B*. As soon as train arrives at *B* and staff is replaced in column either *A* or *B* can send another train on. This is done by an electro-magnetic lock.

A certain number of staffs is allotted to each section. In our case we allow 32 per section, and each station starts with 16. *A* could then send 16 trains to *B*, and *B* could return him 32, or, as they do in practice, they alternate roughly.

Each station has a staff column holding the staffs, which is locked and sealed up, so that it cannot be opened without breaking the seal, even if a key could be obtained, and these keys are jealously guarded and held by electrical employees only.

Staffs are made of steel bicycle tube, 20½ inches long by 1½ inches diameter. There are five brass rings on each, four of them being equidistant, and the last one varies. At one end is a brass head on which the name of the section is stamped or engraved, and the other end is closed up, unless it is a keyed staff, with which I will treat later.

The staff column consists of two parts, a pillar for holding the staff and a head in which is contained the electrical mechanism. The pillar is slotted right through and corrugated, so that the staff can slip up and down but cannot be withdrawn owing to the rings. The slot is continued through the head, ending in an enlarged aperture at the left-hand side. A staff once in this aperture can be withdrawn. On the front and back of head are screwed two cast-iron projecting pieces, hollowed in such a manner as to prolong the aperture abovementioned. These are known as the foot and tail pieces. A staff cannot be withdrawn through the head, but can be inserted at any time. The end ring of the staff serves as a guide through a groove cut in the tail piece, and unless this is exact the staff cannot be withdrawn nor inserted. Working on a centre pin, there are five metal discs having four slots each cut in the periphery, into which the tube of the staff fits. These slots are at 90° apart. One slot is always opposite the aperture, and a contiguous one opposite the slot from the pillar. To insert a staff it is simply placed in position and pushed forward, when the discs rotate and the staff passes into the pillar. A pawl controlled by an electro magnet prevents the withdrawal, which, of course, is in the opposite direction.

The electro magnet is controlled by two batteries, one the line battery from distant end, and a local battery. The electro magnet is a closed magnetic circuit and so wound that with one battery only there is scarcely any perceptible magnetism, but when two batteries are used opposing one another consequent plœs are formed. When the two batteries are in series there is again no magnetism. The magnet is hinged and carried on a right-angled lever so that the bottom end projects downwards into the staff pillar or magazine, and when staff is brought up and lifted it lifts the magnet up. The pole faces of the magnet rest on an armature to which is attached a pawl holding the discs in place. If magnet is energised it lifts the armature with it, and releases the discs, which are free to rotate and then allows staff to be lifted into the aperture, where it can be withdrawn. The rotation of the discs reverses the line and earth wires, so

that the incoming current is in the reverse direction, though the lock and another staff cannot be obtained. If the staff is replaced in the same column the discs rotate backwards and reverse again, thus changing the direction of current back to what it was before. If taken to the other end and put in there it reverses that battery, and the result is the same as before, and a staff can be obtained at other end. To provide against the staff of, say, *AB* section being placed in column for *BC* section, the staffs have a different spacing for the end ring, which fits in the tail piece. We use four different staffs, known by their color as red, blue, white, and green. The staff of one color will not go into any other column, as the spacing of the ring on the staff and the groove in the tail piece is different; otherwise, they are all alike. Red and blue are generally used on alternate sections, and white and green for closing up, and for junctions where there are more than two columns.

Automatic Staff.

To economise personnel at stations and sidings which are used as train working stations only, the automatic staff was devised. By means of a switch the two line batteries are kept on the line all the time. When there is no staff out, the batteries are opposing and no current is used. To take out a staff the need be no one at the other end. If the local battery is switched on, the line battery at the home station is switched out and the staff can, if all is in order, be taken out with the help of the battery current from the advance station. As soon as it is taken out, however, line and earth are reversed and batteries are now in series and a heavy current flows through the line, but as it is in the wrong direction no other staff can be taken out till the staff is replaced. It is very economical of station staff, but is very rough on batteries and requires a good deal of maintenance.

Block Instruments on Double Lines.

In this case we have not to provide for crossing trains in opposite directions, but for forwarding trains on only, the up trains taking one road and the down trains the other one. The staff cannot well be used, therefore, as the staffs would not be returned, and would all accumulate at one end. There are a great number of instruments devised for this work, amongst which may be specified Winter's, Preece's, Tyers', Spagnoletti's, and the single needle block. Some of these have only two positions, and some three positions, and some use only one wire and others three wires.

A block instrument consists of generally a dial with a magnetic needle for each line of rails, or a miniature semaphore, one or more keys, and a switch. On two position instruments the dial shows only *Clear* and *On line*, whilst the three position instruments show *Blocked*, *Clear* and *On line*.

As it is most essential that a block instrument should show the actual state of the line, which two positions cannot do, three position instruments are generally used, and these usually take three wires : one for the bell and one for each line up and down. In Western Australia we use two block instruments, one the Winter's block, which is a two position, one wire instrument, and a three position, three wire block, which was invented by myself. The Winter block has two dials, a plunger for bell and signals, a bell, a black button and a switch. Normally it stands at *Clear*, but line is considered blocked, and *Line clear* is asked for each train, though the dial does not show it. On the train entering the section, train on line is given a bell and acknowledged, and the needles at each end placed to *On line*.

The movement of the needles from *Clear* to *On line* are controlled by relays in the instrument, and the switch, which has two positions, *Off* and *On*. Switch is placed to *On* prior to acknowledging the *Line clear* signal, and by reversing the battery alters the relays and allows the sender to alter the needles by pressing the black button and sending a current on line. When train arrives switch is placed at *Off* and train arrival signalled, which permits the rear station to alter the needles back to *All clear* by means of the black button.

It is not a satisfactory instrument, as it does not show correctly the state of the line ; the switch is not locked up, and can be moved any time. It works fairly well considered as an instrument only.

The three position instrument was designed to give greater safety. It is not possible for one man to alter the indicators except to block the line. It consists of two dials, one for each up and down lines, a bell, a plunger for bell, two switches, and three buttons—black, red and white. Both dials and switches show *Closed*, *Line Clear* and *On Line*. The normal position is at *Closed*. Signals as per an arranged code are exchanged on the bells. The dials are also marked *Train going to* and *Train coming from*, the first being colored black and the second red. In this instrument the switches can only turn one way, and once started must go completely round the circle. The black or *Train going to* switch has two locks, one at *Closed* and one at *On Line*, and the red switch has one lock at *On Line*. If *A* wishes to send a train to *B* he asks permission on the bell. *B*, if he can take the train, acknowledges it, turns his red switch to *Clear*, and presses the black button. This releases the lock at *A* and allows him to turn his black switch to *Clear*, when the needles register *Clear*. On train leaving, *A* gives the departure signal and turns his switch to *On Line*, then throws both needles to *On Line*. *B* acknowledges, and turns his switch to *On Line*

also. Both instruments are then locked and cannot be released except by the train passing over a rail contact at *B* or by both men agreeing to cancel and pressing the red and white buttons simultaneously. Both buttons must be used together, the only effect of using one alone is to ring the bell. The rail contact at *B* controls a battery and when operated by train releases lock on *B* switch and places both needles to *Line Closed*. *B* turns switch to *Closed* and releases *D* by means of the black button. *A* turns switch to *Closed* and operation is complete. No signal except the *On Line* can be obtained without the concurrence of the two signalmen. The instrument is also designed for locking up with the semaphore, in which case it would be lock and block, but so far it has not been found to be necessary.

Lock and Block System.

A step further in advance is made by the lock and block system, the best known example of which is Sykes'. In this the instrument locks up the semaphore lever, so that the signal cannot be pulled off unless permission is granted by the advance station.

It differs from other blocks in that each station has an instrument for each line of rails up and down, and not an instrument for the section both up and down. The instrument containing the lock is placed on a shelf directly above the lever to be locked. The lock consists of a powerful permanent magnet, with two coils of wire wound on soft iron projections attached to same. When the lever is home the soft iron armature is pushed up against the magnet and held up by the magnetism. A current in one direction strengthens the magnets, and holds the armature tighter. A current in the reverse direction weakens it, and allows the lock to fall. There are three strong rods connecting the instrument with the signal lever, passing down through the floor into the locking frame. These are called the lock rod, switch rod and train accepted rods. The indications on the instruments are given by means of discs falling or rising, instead of by a needle. There are two windows in the face of each instrument, the top one showing locked, or free, and referring to the signal lever, the bottom one showing Closed, Train Accepted, or On Line. There are three wires for each set of instruments, one the Up Lock line, the second the Down Lock line, and the third the bell wire common to both lines. Each movement of the lever actuates the rods described above. The lever is locked in two positions first when home in the frame with the signal at danger, called the front lock, and second when the signal is pulled off, called the back lock. At each station is also fixed a treadle, or tail contact for each line of rails, which operated the back lock by the passage of the train. When the lock is discharged, and the lock rod falls, it lifts a piece of steel commonly called the tappet, out of

the notch in a horizontal slide bar attached to the lever and working inguides in the locking frame. As the lever is pulled over the tappet drops again into another notch in the lever bar, and the lever is back-locked with the signal at danger. This second notch is so cut that the level can be put back far enough to put the signal to danger ; but not far enough to unlock any conflicting parts until the lock itself is fully discharged. Let *A*, *B*, *C* be three stations. *A* asks a bell for permission to send a train. *B* grants it and presses his acceptor key. This not only unlocks *A*'s lever and shows *Free* at *A*, but causes *B*'s train accepted rod to fall, showing the disc *Train Accepted* at *B*. *B* cannot press acceptor again, as the fall of the rod blocks its movement inside the instrument. *A* pulls off his signal and allows train to proceed, and gives *B On Line* on bell. *B* replies, and turns what is known as the switch hook, so that it embraces the spindle of the acceptor key and prevents same being moved at all. This action also drops the *On Line* disc at his own station and raises to Danger a miniature sempahore arm on top of *A* instrument. The train entering section discharges *A's* back lock by means of the treadle and *A* can now put his lever back in to the frame. *B* obtains *Line Clear* from *C*, who frees his lock, and when the train arrives and passes over *B's* treadle *B* can put his lever back and accept another train from *A*, after turning back his switch hook and restoring *A's* miniature semaphore to *Off*. The action of putting back the lever returns the indications to Locked and Closed on each instrument. Not only are the instruments locked against manipulation, but when the lever is pulled off the switch rod disconnects the line from the lock and connects it to the treadle. At junctions and yards a large number of subsidiary appliances are used and the arrangements are very intricate and complex, but there is no time to describe these and I must pass on to automatic block.

Automatic Block.

Although train bars, treadles and insulated rails are largely used in the above systems, none of them provide against one danger—viz., that part of the train be left in the section. If only the engine arrives the line can still be cleared and another train accepted.

This the automatic system does. The principle is very simple. The railway is divided into sections, each pair of rails making part of an electrical circuit, distinct from any other pair. The rails of one pair are isolated from each other by means of the sleepers, special means being employed with regard to points, crossings, interlocking rods, etc. At each end of the section the rails are isolated from the next section by wooden fishplates.

A battery or an electric generator is connected to these rails, and also to an electric motor, or magnet on the semaphore itself in parallel, so that when there is nothing on that pair of rails the current actuates the signal motor, and holds the signal off at Clear. On a train entering the section the wheels short circuit the current so that there is none left for the motor, and the arm flies back to *Danger* and remains there, till the train passes at the other end clear of the insulating fish-plates. The current then passes again through the signal motor and pulls the arm off to *Clear*. This is entirely automatic and dispenses with signalmen entirely. At first sight it may seem that the insulation between the rails would not be sufficient in wet weather, but in practice by the use of special apparatus it is found to work well, though of course there is a very heavy leak. We have not yet any examples of entirely automatic working in Western Australia, but we have a number of insulated sections working in conjunction with signal boxes at junctions and yards under similar conditions. In practice there are generally two arms on each signal post, at the entrance of each automatic section, one showing the state of the first section and the other that of the section ahead. The latter is only a warning signal, but is necessary as a guide to the engine crew, as the sections under this system are generally very short. In some systems the rails are insulated and utilised to light lamps in the driver's cab, green for go ahead, red for stop, and still another employs a trip lever which puts on the brake on the engine should the driver pass a signal at danger. The Railophone, recently brought out, provides means for talking to the driver or guard, and giving signals in the cab, or brakes on whilst train is in motion.

Electrical Interlocking.

Without even touching electro-pneumatic and all electric systems, electrical interlocking is too large a subject to deal with in a general paper. Each place has to be dealt with under its own special conditions, and even in a small yard a very large number of the appliances described come into play. The idea is to so lock the signals and conveying points that no train can be admitted to a line on which there is anything. This is generally done by insulating the line itself, as described under automatic working, and through that locking the levers either with a lever lock or Sykes lock, which prevents the lever being pulled, or else by a reverser on the signal post, which will not allow the arm to come off so long as there is anything on the line.

In concluding this paper, which I am afraid is very sketchy, as I have been able only to go into general principles, I cannot

do better than give the following rough totals of the electrical appliances used on our railways, as follows :—

Lock and Block Instruments	38
3-Position Block Instruments	34
2-Position Block Instruments	42
Staff Columns	180
Telegraph Instruments	35
Telephones and Telephonettes	950
Treadles or Rail Contacts	220
Total Number of Miles of Line Maintained	9,000
Total Number of Poles, Wood	25,000
,, ,, ,, Iron	27,000

Discussion.

Mr. Edmiston said he was just sufficiently conversant with the subject of signalling and telephony to realise that Mr. Dowson had given them but an outline of all that was implied by his subject, and he was doubtful if even that was not sufficiently comprehensive for most of them. Mr. Dowson's paper, of course, was not one which was not subject to criticism—it was a descriptive paper and as that alone it served its purpose very well indeed. If he would be permitted to add a personal note he might state as a contracting electrician he had something to do with apparatus of a kindred nature and some years ago his firm was asked to submit designs for a street fire alarm and communication system for the Melbourne and Metropolitan Fire Brigades Board of Victoria. They were successful and received a fairly good order and ultimately equipped some dozen fire stations in the area. This experience had the effect of teaching them one thing of real value among a whole lot of matters of comparatively minor importance, and that was that this branch of engineering was a department by itself and had better be left alone by outsiders. In connection with this work they designed an entirely new and special line indicator in the form of a dropping shutter, such as is used in telephone lines. The system being a closed-circuit one, the shutter had to be of delicate workmanship. Each element was provided with two shutters, one superposed on the other and operated by the same armature. The use of the front shutter was for indicating a telephone call, but if both fell it indicated a " turn-out " call or fire alarm call on that particular line. In the latter case the result was most dramatic. The horse covers were automatically removed and their stall doors opened. If a horse did not get out of his stall very smartly he got a stroke of an automatic cane. Bells rang in every conceivable place and the house was brought down generally. It caused considerable discussion and we were

favored with notices in several scientific journals, particularly regarding the line indicator, and we were extremely proud of that. He felt sure his partner nursed secret jealousy in any part he had in the origination of the drop-shutter. He had his judgment for his secret thoughts on the mental attitude he (Mr. Edmiston) had adopted towards him, and such was the perversity of human nature that he believed they were still equally ardent of their individual claims in the matter, although, as a matter of fact, the thing was never any good and was ultimately abandoned. One striking feature that was brought to one's mind in reading Mr. Dowson's paper was the wonderful advance that had taken place in signalling since the time of Sir Francis Ronalds, the inventor of the first real telegraph. Soemering came before Ronalds, but he used a large number of wires (up to 30) and the signals were made by means of bubbles of gas arising from the decomposition of water, which meant that every pair of wires was united through the bottom of a glass tube and the action of the current in passing into the tubes and out again had the effect of decomposing water into its constituent elements—hydrogen and oxygen—and the bubbles could be seen rising to the surface, and that is the way the message was detected. Ronalds made a tremendous advance in 1816, and was able to make all necessary signals with a single circuit. He used static electricity from a frictional machine and carried signals over eight miles of line insulated with glass tubes laid in a wooden trough embedded in pitch. His receiving apparatus consisted of a pith-ball electrometer and the method of signalling was most ingenious. The pith-ball electrometer was, he dare say, familiar to most of them. If two little pith balls were held by a delicate silk thread and charged with frictional electricity they were immediately diverged—one would repel the other until they were discharged again. At each end of the line was a clock-work contrivance, having a dial provided with a small opening. On the second wheel was attached a strip of paper bearing all the letters and numerals, so that the same letter or numeral could be exposed at the openings simultaneously. As a certain symbol appeared at the opening the sender sent along an electric signal, which caused the pith balls to diverge, indicating to the operator at the other end the symbol intended. That is, assuming that both the clocks were in perfect synchronism and the wheel revolving came to letter "a," he immediately sent along a charge which diverged his pith balls and the operator seeing the alteration of the pith balls dotted down "a," and so on through the message. The method of calling up the other end was by sending along an electric charge, which fired a small pistol at the other end to call the attention of the receiver. This operator then adjusted his dial at the "prepare" signal, which placed his dial in synchronism with that of the sender: then he proceeded to receive the message. At the beginning of every

message the clock dial had to be readjusted to a given point and then the message began. Ronalds was greatly neglected for the service he rendered humanity. He was really the father of electrical telegraphy. He had a very bad time in England, and was really about thirty years before his time—before Weston, Cooke and Morse. He ultimately received a niggardly pension of £75 for, as was wittily said, the Government could never quite forgive him for his having been wronged by them. What he did, what Weston, Cooke and Morse did after him, made possible the wonderful developments of the present day, including the intricate and valuable system of signalling outlined by Mr. Dowson in his paper.

Mr. W. Leslie said the paper covered a branch of engineering in which few members had had much opportunity of becoming intimately acquainted, but he thought Mr. Dowson had been able to show that it is a most interesting branch and one that appears to require a great deal of study and attention. I think most of us will make our train journeys with confidence after this when we have been taught the amount of engineering science which has been brought to bear to make our journeys safe. I must confess, after hearing the paper Mr. Dowson has given us so much to think over that I do not feel equal to saying anything in the way of criticism.

Mr. Lawson: There is no doubt about it, the subject has been shown to us as very much wider and covering very many more branches of engineering than railway signalling. Like Mr. Leslie, I agree when we get the paper in print, if we cannot criticise we shall no doubt ask many questions—not so much for the sake of gaining much information, but more in a way from a layman's point of view, because we really are, more or less, laymen in this particular branch of railway engineering, so that we may be able to feel in our own way as Mr. Leslie says, that we are really safe in travelling over the W.A. Railways. I think we can safely say this: the records of the W.A. Railways, as far as we know it, prove that this particular branch of railway engineering in this State is not at all lacking and compares very favorably with that of any other State in the Commonwealth. I am sure we are deeply indebted to Mr. Dowson for the paper and the trouble he has gone to to illustrate by means of instruments in daily use.

Mr. Dowson said he was sorry there was no more discussion on the paper. He was afraid there would not be. Railway signalling was not a matter that was open to criticism or discussion. Practically it did not enter into competition with anything. All he could do in reading such a paper was simply to give a description of the various systems employed upon the

railway and he did not see even if he went on further with the matter how it would invite criticism. In the Old Country, where of course they had different railways and different systems of signalling, it was easy to get up criticism, but here, having practically only one railway, there was only one system.

THE PROSPECTS OF ELECTRICAL DEVELOPMENT IN WESTERN AUSTRALIA.

(By H. Edmiston.)

Prefatory.

In presenting this paper I desire at the outset to say that I make no claim to originality in respect of certain matters that it contains.

The recent decision of the central authority to establish a large central supply capable of dealing with the whole metropolitan area, however, is an event which places beyond discussion any question of dispute that might otherwise have been possible regarding the matter of control in the event of a large scheme of electrification coming up for consideration. It makes the possibility of future development doubly easy. It is surrounded with advantages that are at once unique and are so far-reaching in this respect that once they are realised this State is likely to be the envy of older and less favored countries.

Organizing Ability Needed.

As matters stand at the present time, however, some of the local governing bodies who have expended large sums of money in building up and in acquiring control of their electrical supply industries would be placed at some disadvantage as compared with their less enterprising neighbors. In some cases this feature might be of so serious a character as to warrant the greatest care in dealing with the matter. But if we take the view that these more enterprising localities deserve the fullest recognition as the pioneers of electrical enterprise, because to their enterprise the community will, as a whole, be indebted for any large development that can take place. It would therefore seem generous and statesmanlike for the central authority to take over their liabilities in respect of such expenditure, consolidate the whole, and apportion the annual charges on the capital over the cost of all the power produced. This would not be an essential feature of a great scheme of electrification, although it would seem to be a wise and proper one. Science, as we have seen, has provided us with all the other essential materials for such a scheme and it would seem that all that is now needed is sufficient organising genius to put matters in train, when once it can be shown that we ourselves possess the necessary resources to justify the adoption of a large electrical enterprise.

Resources.

As regards our own resources :—These must necessarily consist of a cheap and adequate source of natural energy within reasonable distance from the centres of demand, and the demand itself must be of sufficient magnitude in order to produce enough revenue to cover the cost of operation, administration and capital.

This country has not been favored by nature in the way of providing it with the necessary snow-clad mountains and falling streams to deliver up to us the sun's radiant energy in that way and perforce we are compelled to direct our attention to what nature has seen fit to give us in the accumulated energy in our coal fields.

Up to the present time we have gathered much speculative evidence as to the practicability of utilising this energy direct and conveying it in the form of electricity to the various centres of human activity, instead of carrying the fuel by rail, etc. Some minor developments have already taken place in other parts of the world and one very large scheme is now in process of development by means of which it is proposed to entirely supplant the use of coal in the City of Boston by electrical transmission from the coal fields of Pennsylvania.

Mr. S. L. de Ferranti, in his presidential address before the Institution of Electrical Engineers, 1910-1911, dealt with the larger aspect of the matter in a way that it has never been previously treated. In one part of his address he expresses the opinion that " the distribution of energy in the form of electricity instead of coal can only be effectively carried out when it can be done in such a way that it is available for all the purposes for which coal is now used, and this can only be the case when the conversion is effected at such an efficiency as will cause the electrical energy to represent a high percentage of the energy in the coal. Failing this, no scheme for conversion at the pit's mouth and delivery in the form of electricity is sound."

Such an ambitious scheme as this would seem to outline is quite beyond our hopes, and even if science has made such a proposal possible, say in Boston or in England, it is still for us a somewhat distant dream and would require for its success such a magnitude of output as will not be possible in this country for some years to come.

This does not suggest for one moment, however, that the time has not arrived or is at least approaching when we in this country will have to rigidly establish the actual process by which it is ultimately to be accomplished, and when it can be shown that electric power can be transmitted from our coal fields at a cost which does not exceed the present cost of producing it

locally, or even a little more, then it is evident that the time will have arrived when it would be injudicious to expend any more money in developing the present system. We have never had an all "Steam Age," and it is improbable that we will ever realize an all "Electric Age," and if we are to accomplish the making of the Electric Age even in the sense that we have had a Steam Age, the process will be a gradual one, and, like all things else, its development will have to conform to a gradual course of evolution, but it will rest with ourselves how direct we can plan that process if we are to make the best of the changing conditions as they present themselves.

It must be conceivable to almost anyone that if we are to await the time when the demand for electrical energy shall have developed sufficiently out of the existing methods of providing it before we can raise the necessary courage to proceed in the way that nature, science and circumstances demand, we may never realise it. Moreover, by that time we may have evolved for ourselves in the interim such a vested interest in the existing appliances as may later on place the ideal far beyond our grasp.

If we are to benefit by the experience of older countries, we must avoid the error of overcaution and be entirely guided by commonsense and a bold faith in what science and our own reason teach us. We must avoid those pitfalls which, although excusable under private exploitation in the past, would be intolerable at the present time under the new condition of things. We must therefore reverse the old helpless policy of allowing the demand for this commodity to lead the enterprise of providing for it, and cause the means of supply to take precedence of the demand. We must assert abstract principles such as quicken the pulse of humanity instead of proceeding in a cautious, fragmentary and hesitating manner for want of faith in any higher standard that what is convenient for the day.

While it will be wise to avoid too much caution in dealing with a matter of such far-reaching importance to the community, it will be necessary to proceed with reasonable deliberation, and it is not suggested that a great enterprise should be launched until the fullest knowledge of all that relates to every detail has been acquired and considered in all bearings.

Members will realise, I think, the difficulty which anyone without official authority would experience in procuring the necessary data to enable him to deal with such a large matter with reasonable exactitude. The electrical and other engineering industries in this State are not of sufficient importance compared with other industires to warrant the compilations of much statistical data and such as is available would be of little use for this purpose. The community measured by the standard of its

industries is not a large one as yet, and I rely on personal knowledge gained from intimate experience of most of the large electrical works, and other industries concerned, to supply me with the necessary data for this preliminary investigation.

The possession of this information, together with the interest which the subject may have for members, and the discussion which may thereby be prompted alone has induced me to essay an attempt to work out the position which this State occupies at the present time in relation to the successful application of the principle of electrical transmission of energy from our coal mines. Although the figures adopted cannot be accepted as final, I am hopeful that the margin of error is not large enough to affect the general result.

It is, of course, assumed that there is a sufficient store of energy in the form of coal at the Collie mines, or that perhaps this may be supplemented in time by new and perhaps more important discoveries at even shorter range than the Collie River district. That being so, the question of our capacity to use and consume energy in the form of electricity would seem to be the crux of the question, for it appears that in every other respect this State is placed in almost unique and wholly advantageous circumstances for the better utilisation of its available resources.

I think there can be no doubt in the minds of members that there will be a stage reached as regards commercial economy when a direct electrical transmission of energy from the mines must leave the other method behind and that a point would occur where their respectively descending " cost curves " must meet and cross each other.

As a preliminary to this investigation, I have made a series of rough estimates in order to ascertain this approximately, and it would appear that this event would occur when the output reaches a magnitude of between 40 and 50 million units per annum. This phase of the question may have more than passing interest for members, but one important feature that will be clearly demonstrated by anyone who undertakes the task of examining the matter is, that any transmission scheme, designed for an output such as this State is likely to require for some time to come, will necessarily be handicapped at the initial stage by certain engineering features which affect the cost of construction and, consequently, the cost of production. For instance, if we remember that the conductors would in this case have a length of over 100 miles, it is self evident that it would be bad practice to construct the lines of materials of just sufficient size for the initial requirements.

It might be advisable, in fact, to make them large enough for three or even four times that capacity. Again, the continuity of service which would be demanded from such a transmission would probably be of sufficient importance to warrant the installation of a twin line or possibly of two single lines. The capacity of such a scheme as would be needed at the start would probably be too small to find any solution in the fact that 20,000 k.w. is about the maximum economic load that can be carried on a single line, and, as we have seen, a double line may be necessary.

It is evident, therefore, that the conductors and their supports will have to be made as large as possible, perhaps limited only by the greatest economic capacity of any line, and as a consequence it is probable that the initial scheme will have to carry some non-productive capital expenditure.

With the idea, therefore, of arriving at some conclusion in respect of a transmission scheme it will be necessary to consider what our prospective capacity for using electricity, on the basis of a large and comparatively cheap supply, is likely to be.

Present and Prospective Demand.

Considering that our total demand for electricity in the Perth and Metropolitan area at the present time does not exceed by much 8,750,000 units per annum, one might be lead to assume, in view of the foregoing figures, that it will be a long time before this community can develop sufficient demand to justify even preliminary considerations of such a large scheme of electrification.

We are in the habit of estimating electrical quantities in mere units, costing at the rate of sixpence each, and used almost exclusively for lighting. We speak of an electric light account and the electric light works and the electric light engineer, and so on, because we have not yet acquired the habit of associating the electric supply with much else than lighting.

If besides lighting we were using electricity for a few only of the other purposes for which it could be economically applied in our homes under well thought out conditions, say for heating and cooking, we might require anything up to fifteen times the amount we are at present in the habit of using.

Instead of, say, 8 or 10 units per month for lighting our homes, we should probably, in addition to this, use another 150 units to meet some of our other equally urgent needs.

At the present time probably 80 or 90 thousand persons live within easy range of such an electric supply as could be brought from Collie, and if half only of these people used electricity

for cooking, they would absorb about 15 million units per annum; and this quantity alone is greater by 45 per cent. than all the current used at the present time in Perth and Fremantle, and all the surrounding suburbs, to light their houses, streets, shops and offices; to drive their factories and workshops and work their tramways.

The quantity required for cooking and heating is quite small as compared with what could be economically used if some of their other and larger needs were catered for.

The question of applying electric power to work our inter-urban railways is, I believe, being seriously considered at the present time, and I believe also that it has been suggested that the Perth to Northam railway might be electrified in the event of the Trans-Continental Railway coming that way.

The Bellevue to Fremantle traffic (excluding Northam and Kalgoorlie trains) is probably of the nature of 900,000 train-miles per annum, including passenger, goods, mixed, water and coal trains, but not including ballast, shunting, casualty or inspection traffic.

If we take the average speed of the trains at 20 miles, and the average weight at 300 tons per train, including the locomotive; then, excluding any refinements in the calculation involved by the number of stops per mile and the acceleration losses due to these stops, the consumption per train mile will not be much less than 10 units, and therefore something like 9 million units would be needed for the Bellevue-Fremantle traffic.

On a similar basis of calculation about 10 million units would be needed on the Fremantle-Northam line.

Again, if a transmission from Collie was adopted the cables would traverse a route close to the Bunbury line, and it goes without saying that this line would also be electrically equipped. The Armadale section runs about 240,000 and the Bunbury service about 670,000 train miles per annum.

Altogether about 28 million units would be required for railways.

Flour mills, saw mills, tramways, metropolitan pumping station, and many industries, which now use a little, and others that cannot afford electricity just now, would probably consume another 15 million units.

We use about 4 million units per annum for lighting just now. At a reduced price this might easily be increased to 6 million units, but enough has been shown to indicate that there would be a very large demand if the price is commensurate with the work to which the current can be applied.

The total prospective output would therefore be :—

Railways	28 million units
Domestic	15 ,, ,,
Tramways and Industrial ..	15 ,, ,,
Lighting	6 ,, ,,
	—
Total prospective demand...	64 ,, ,,

There are, of course, other industries that have not been developed in the country which might also be introduced, such as the smelting and refining of copper and the production of fixed nitrogen, but these are more of a speculative character and would require some special study before an opinion could be stated in respect of their value for our purpose. In any case I have adopted the round figure of 60 million units as the probable demand which might be anticipated if the cost of production works out all right.

Load Factor.

With regard to the important question of load factor. There is no mathematical process by which this can be worked out, and, its determination must be largely a matter of judgment and experience. If one attempts to plot a suitable curve the process is soon found to be too complicated and want of exact data is likely to lead to serious error. In short, in order to arrive at a close approximation much labor would have to be expended in obtaining suitable data, but such exactness can be dispensed with provided it is reasonably assured that there is likely to be no extraordinary peak in the load curve. Avoiding then such an extraordinary load factor as that suggested by Mr. de Ferranti in his address, namely, 60 per cent., I have come to the conclusion that it would not be unreasonable to expect a value of 35 per cent. with such a diversified load as the one I have outlined. This will not seem very high when it is remembered that the Sydney Corporation plant has a L.F. of 37 per cent., although it is used for lighting and industrial purposes only.

Nominal Capacity of Initial Plant.

If the plant is to yield an output of 60 million units per year, with an L.F. of 35 per cent., its capacity will be :—

$$\text{K.W.} = \frac{60{,}000{,}000 \times \frac{100}{35}}{8{,}760 \text{ hours}} = 19{,}572 \text{ K.W. } (35{,}000 \text{ I.H.P.})$$

Say 20,000 kilowatts, and this will represent the peak load and therefore the capacity of the operating plant.

Capital Cost.

This will now enable us to deal with the important question of capital cost.

Existing Appliances.

At the present time there is invested and about to be invested in the electric supply industry an aggregate sum of something like £800,000, excluding, of course, tramway lines and rolling stock, but including £200,000 for the new State power Station, all of which must be an ultimate charge on the concern, no matter what principle may be ultimately adopted in the distribution of the capital charges. The average interest rate works out at about 4.15 per cent. per annum. As a matter of fact, about 80 per cent. of this capital carries interest at about 4 per cent.

To this £800,000 let us add the sum of £250,000 for the purpose of extending and improving the low tension feeders and street distributing mains and appliances in order to bring the system into line with the enlarged service.

Voltage.

As we have seen, the 100-mile transmission line will require to be large enough to carry 20,000 k.w. and since it will be wise to divide the conductors into twin circuits the capacity of each circuit will be 10,000 k.w., either of which would be capable of maintaining the service temporarily in case of breakdown of the other ; but, as it would be bad engineering to limit the size of these lines to the present requirements, it will be advisable to provide for an increased demand, and as the limiting capacity of any set of conductors is 20,000 k.w., it will probably be judicious to bring them up to the full size and make the lines permanent.

The design of long distance transmission lines is one that presents so many and conflicting features as to almost stagger the mere layman. For instance, the selection of the most economic voltage alone is a matter involving the widest knowledge and experience, and cannot be reduced to any mathematical formula. So many variable and diverse considerations are involved, affected by the locality, altitude, average meteorological conditions, etc., as to make the subject a special department by itself.

During the last few years I have accumulated a considerable amount of data relating to the matter, and I am fortunate in having in my possession some very recent information bearing on the subject, and an interesting paper might be prepared out of mere disconnected facts relating to the strange phenomena peculiar to high tension transmission.

It appears, however, that if a standard voltage could apply to any given transmission 110,000 volts would be the selected pressure for operating over 100 miles, and on that voltage this scheme is based.

Frequency.

The frequency of the alternating current would probably have to be about 40 cycles, which is the lowest that can be used on lighting circuits, especially for arc lamps. Closer reasoning of this matter might cause the figures to be altered, but neither that nor the effect which the frequency has on the cost of the appliances will be likely to affect the main consideration here involved.

Transmission Lines.

These matters being decided, the operation of working out the economic size of the conductors can be arrived at. The amount of copper that can be economically used (or the amount of current that can be economically conveyed over a given size of conductor) is fixed by the cost of the copper, the cost of the generating plant, the cost of producing the power, the rate of interest on the investment, and other considerations. All these factors are embodied in various formulae for working out the amount of copper (or aluminium) and the economic size of the conductors to carry a load of 21,928 kilowatts with a power factor of .80 over a distance of 100 miles, if made of copper, would be ½ inch in diameter and about ¾ inch diameter if made of aluminium. The full load efficiency is 94,35 per cent.

I have estimated on the basis of a twin line (20,000 k.w. each), erected on steel towers spaced about 550 ft. apart, at a cost of £1,549 per mile for the whole structure erected.

Transformers.

As the dynamos cannot generate the full transmission voltage, a set of transformers will be required at the generator end to step up the voltage from, say, 11,000 volts to 110,000 volts, A set will also be required at the receiver end to step it down to a suitable voltage for feeding the current to the various districts. Here it would again be reduced to the required voltage for final distribution.

There would therefore be three sets of transformers and each set will produce a loss of power according to the nature of its use and the method of operating it. I estimate that the full load efficiency (and regulations) would be :—

Generator end eff. ...	98.8%	Regulation	.80%
Receiver end ,, ...	98.8%	,,	.80%
Distribution ,, (average)	98.2%	,,	1.2%

The efficiency and regulation of the transformers on the distribution would not be so good as the others : they would be smaller and therefore more of them would be required, and this accounts for the difference stated.

After allowing for the losses, step by step, including that of the transmission lines, the capacities of the various sets would be, roughly :—

Distribution Transformers	20,000 k.w.
Receiver end (step-down)	20,408 ,,
Generator end (step-up)	21,928 ,,
Total output capacity	62,336 ,,

It will be necessary to add to this total about 20 per cent. as reserve plant ; therefore the total capacity to be installed is likely to be about 73,000 k.w. In all probability the transformers would cost, including switching gear, sub-station buildings and appliances, about 40s. per k.w. installed, and for this item the total cost would be, say, £150,000.

Generating Plant.

The output capacity of the step-up transformers at the generator end being 21,928 k.w., the capacity of the generating plant will be equal to their input capacity, which, after allowing for losses, would be 22,184 k.w.

Besides this quantity of generating plant probably from 20 per cent. to 25 per cent. of reserve machinery would be installed, which would bring the total up to, say, 27,500 k.w.

This plant will possess no special features, as it would not produce any high tension current. It would be of about the same character as that which is about to be installed at the new riverside station on behalf of the State Government. Very little high tension switching gear is used in the later design of H.T. transmission. The system (two lines) would not be operated in parallel on the high tension side, and as the transformers would be treated as part of the line the switching would be done on the low tension side of the transformers. As the cost of most of the switching appliances is provided for in the transformer estimate an allowance per kilowatt of £15 for the generating plant should amply provide for it. This would make the estimated cost of the power house and equipment £412,500.

The total estimated cost as outlined above will be :

Capital already invested	£800,000
Extensions and alterations to existing distribution appliances	250,000
Transmission lines	154,900
Transformer sub-stations and equipments	150,000
Power house and equipment	412,000
Total capital cost	£1,766,900

It is now possible to work out the cost of production and delivery of the current at the consumer's meter.

Cost of Production.

The first item to be dealt with is the question of transmission and transformer energy losses, as this must be added to the working expenditure.

I have adopted a well-known method of working out these losses by dividing the daily load into periods of full, half, and no load, then calculating each stage separately and adding the results. This method is reasonably correct if the ratio of full-load hours to half-load hours is taken at about 3 to 2. For a 35 per cent. load factor the daily cycle of operation may be taken, therefore, as being approximately 6.3 hours full load, 4.2 hours half load, and 13.5 hours no load.

The full load efficiency of the transmission transformers would be about 98.8 per cent., and the regulation .8 per cent. ; the iron loss will therefore be .4 per cent., and the all-day loss will be, taking the step-up transmission transformers, which have a full load capacity of 21.928 k.w., as an example :—

Load Loss.

Iron loss in k.w.,	all loads	$-21,928 \times .004 =$	87.712 k.w.
Copper ,,	full load	$-21,928 \times .008 =$	175.432 ,,
,, ,,	half load	$-175.432 \times (\frac{1}{2})^2 =$	43.858 ,,

Energy Loss (daily).

Iron loss in k.w. hours	$-87.712 \times 24 =$	2,105.088 k.w.h.
Copper ,, ,,	full load $-175.432 \times 6.3 =$	1105.222 ,,
,, ,, ,,	half load $-43.857 \times 4.3 =$	183.057 ,,
All day loss on 35% load factor ...		3—3 367

Average All-day Efficiency.

Output in k.w. hours – (21928 x 6.3) + (10,964 x 4.3)
= 184,195 k.w.h.

Input in k.w.h. – 184,195 + 3,393·367 = 187,588·367 k.w.h.

All day efficiency is therefore $\frac{184,195}{187,588·367} = 98.2\%$.

(Note.—K.W.H. = Kilowatt-hours or units of electrical energy.)

The all day efficiency of the step-down transformers at the receiver end would be of the same value, but the distributing low tension ones would be more numerous, therefore smaller, and their efficiency works out at a little over 97.31 per cent. The line loss is worked out on a similar basis, and the average all-day efficiency of this is about 94.35 per cent.

The efficiency of an ordinary distributing system for lighting and small industrial use with a well planned sub-station lay-out will probably average out at about 95 per cent. This is a figure commonly adopted, and I believe represents a fair general average. In this proposal the current used for railway purposes would be delivered in bulk quantities at the original pressure and the quantity required and the price to be charged is estimated on that basis.

It is probable, therefore, that the distribution efficiency measured as a percentage of the whole output will not be less than 97 per cent.

The nett combined average efficiency of transformation, transmission and distribution would therefore be, taken in their order from the step-up transformers at the generating end as follows :—

Step-up transformer efficiency, 98.2 per cent. ; transmission line efficiency, 94.35 per cent. ; step-down transformer efficiency, 98.2 per cent. ; low tension (distributing) transformers, 97 per cent. ; distribution efficiency, 97 per cent. a nett combined efficiency of 85.607 per cent.

No allowance is made for any saving in respect of magnetising current used by idle transformers, which would naturally be isolated at periods of light load ; moreover, the line losses would be much smaller at the inception of the scheme, since they are double the size of those calculated for the loss.

However, these losses are taken as represented by an efficiency of 85.60 per cent., and are added to the cost of production.

The next item for discussion is coal consumption. It is assumed that the cost of coal in the bunkers would be 4s. per ton, and that this fuel would have an average evaporative value of

5½ lbs. of steam per pound of coal consumed. The steam consumption is put down at 15 lbs. per k.w.h., based on an operating factor for the machinery of about 70 per cent. For steam transmission losses 5 per cent. and for electric transmission distribution and transformer losses 14.4 per cent. is provided, the latter being based on a nett combined efficiency of 85.60 per cent., as stated.

The gross steam consumption, therefore, works out at 18.445 lbs., or say 3.3536 lbs. of coal per k.w.h., which at a cost of 4s. per ton comes to .072 pence per k.w.h.

Upkeep and renewals, including the cost of labor in effecting this, is covered by an annual charge of 1½ per cent. on the total capital cost and set down under that heading.

The item "wages" covers the cost of labor in running the works only. The power house would absorb about £16 9s. per day, excluding fitters, blacksmiths, carpenters, painters, etc., whose wages would be included in the item of "upkeep and renewals."

The amount allowed in respect of wages for distributing the current is £38 9s. 6d. per day, and includes the cost of superintendence, attendance on consumers, accountancy and collection of revenue in each district, of which there would probably be about sixteen.

"Management and administration" includes insurance, lega and other professional, and all the usual office expenses. For this the round sum of £7,000 per annum is set down, and other smaller items are included in the following summary of annual expenditure :—

	£	Average cost per unit sold d.
Interest—		
Capital already expended by the various municipalities, £800,000, at an average of 4.15 per cent...	33,200	
Further capital expenditure required to complete the scheme, £966,900 at 4 per cent.	38,676	
	71,876	.287504
Depreciation and obsolescence—		
3 per cent. on capital cost, (£1,766,900) at 3 per cent.	53,007	.212028
Upkeep and Renewals—		
1½ per cent. on capital cost	26,503	.106014
Carried Forward....	£151,386	.605546

Brought Forward....	£151,386	.605546
Fuel—		
90,000 tons at 4s.	18,000	.072000
Oil, Waste Water and Engine House Stores	4,000	.016000
Management and Administration	7,000	.028000
Wages and Salaries—		
Power House, 365 days at £16 9s...	5,999	.023996
Distribution, average 313 days at £38 9s. 6d.	12,042	.048168
Right-of-way charges on transmission lines, 800 acres at 40s. per annum	1,600	.006400
	£200,027	.800110

The total expenditure for the production of 60 million units works out, therefore,at £200,027, which is equal to .800110 pence per unit, covering all charges, and this represents the average price that would have to be charged to the consumers.

The price charged would, of course, vary with the class of consumer, and the purpose to which it would be applied. For lighting a fair average price might be twopence per unit. On a sliding scale the maximum price for lighting would be, say, twopence half-penny and the minimum one penny half-penny per unit.

For industrial purposes, tramways, etc., the average price might be put down at one penny, on a similar sliding scale of charges. Electric cooking and heating would soon become popular at a flat rate of three farthings per unit. For a family of five the cost would range from 9s. 6d. to 14s. per month, according to the plainness or otherwise of the fare.

The Railway Department would be well served indeed if their electric supply cost no more than .6034 pence per unit.

This would produce all the necessary revenue on the basis of the assumed output of 60 million units as here shown :—

Lighting—6 million units at 2d.	£50,000
Tramways and industrial—15 million units at 1d.	51,250
Cooking and heating—15 million units at ¾d.	38,438
Railways, 24 million units at .6034d.	60,339
Total revenue	£200,027

Conclusion.

It may be argued that if a big electric scheme were launched with the present system of utilising the power, the cost of production would not be so very much greater; and that may be so, but each year will increase the difference, and as the load factor improves this difference will be greatly accentuated. In the one case the surplus power will cost .072 and in the other .25 pence, or in that proportion. In the former case its utilisation for new forms of industry is highly probable; in the latter it is likely to be barred for ever. In the one case the way is paved to the realisation of the new era of electric power; in the other, that desirable end can never be attained.

If this great enterprise can be carried out at all, it can be carried out as well to-day as 20 years hence. By that time a demand of 50 or 60 million units may be established and awaiting a cheapened supply, but the capital invested will modify that cheapness then as it does to-day. Then as now a revolution in the electric supply could be accomplished, but if carried out now we will by that time have had all the advantages of such a revolution with a span of twenty years behind.

If put into force now, by the end of twenty years this revolution will have long ago merged into the new electric age of civilization.

Discussion.

Mr. Gardam: Mr. Edmiston's paper evidenced much labor in its preparation, and was served up to them in a most attractive style; members were nearly soothed into accepting what followed. The scheme may be practicable, but he feared in this instance no more sufficient reason than scientific enthusiasm would be found to explain why the Collie scheme should be adopted since it would require nearly half a million more money to carry out and when completed would deliver current more expensively than a system put down at Perth. Assuming Mr. Edmiston's figures as correct, the first question was:—What is the reason for generating current 100 miles away from the point of consumption? The only reason was the assumed saving in transmitting energy electrically instead of carrying it by rail in the form of coal. They found, however, on examination, that the transmission loss in the line and step up and step down transformers was 9 per cent. of the units generated, or 6,390,000 units, which at .676d. per unit generated represented £18,000, and this alone practically nullified the saving in railage of the fuel to Perth. Also by utilising the plant already ordered for the State power house and by installing the rest of plant in Perth, the outlay on the

transmission line, etc., would not be required and thus a saving in interest, depreciation, upkeep, etc., would be made of £38,000 per annum. Mr. Edmiston's total estimated cost was £1,766,900, but were the station erected in Perth they could reduce this by omitting :—

Transmission lines	£154,900
The step up and step down transformers	101,000
Portion of the power house plant already provided in the State power plant	200,000
thus they would save in capital cost...........	£455,900

The cost per annum would then work out, with 9 per cent. less current to generate, as follows :—

Interest on £800,000 at 4.15 per cent.	£33,200
,, £511,394 at 4 per cent.	20,455
	55,655
Depreciation and obsolescence at 3 per cent.	39,342
Upkeep and renewals, at 1½ per cent.	19,671
Fuel, 81,900 tons, at 9s. 2d.	37,537
Oil and stores	3,640
Management and administration	7,000
Wages and salaries	18,041
	£180,886

or .743544 pence per unit sold ; whereas the cost per annum for the Collie scheme was £200,027, or .80011 pence per unit sold. There were no advantages whatever to be gained by generating at Collie instead of Perth, but there were certainly many grave disadvantages, principally interruptions to the supply at this high voltage, and in view of the foregoing figures he could not imagine anyone considering seriously Mr. Edmiston's scheme.

MR. DOWSON : The scheme of distributing electric energy from the Collie coal fields was certainly attractive, but when examined closely it could not, in his opinion, have any real present day interest. It was simply a question between carrying potential energy in the shape of coal and distributing kinetic energy through wires. In the first place, he considered at 35 per cent. load factor was far too high to assume ; 30 per cent. would be very good ; 25 per cent. was more probable. A good deal was made of working up a load for lighting, cooking, etc. ; that would take a long time, and whilst this was being done the plant would run at a loss. Such a scheme was only practical where there was a large manufacturing industry crying out for power, and that certainly could

not be said to be their case. The home market was far too small to allow of much manufacturing industry and owing to high wages and distance from large centres of population he could not see any hope of an export trade. Again, taking extra cost of conveying coal from Collie to Perth: that averaged 6s. 6d. per ton now, but would be reduced to 5s. per ton taken in train loads, as it would be. Here he must say he could not agree with the author as to the probable consumption of coal per kilowatt hour. Averaged over three large British stations—England, Scotland and Ireland—coal consumption was 3.8 lbs. If they generated here on Collie coal at 4 lbs. they would do very well. The extra cost, therefore, per unit, based on a 20,000 k.w. peak load at a prime factor of 25 per cent., or roughly 44 million units per annum, was .13929 pence, or a total of £25,536 to pay for interest and upkeep on transmission line, loss on transmission, extra capital cost on power house, and extra wages paid at Collie, etc., etc. *Transmission line.*—The author gives £1,549 per mile for line, but takes it as 100 miles only. The cost is about right per mile. According to American figures, line will cost £500 for line, £108 for insulators, and £963 for copper, a total per mile of £1,571, and for the 124 miles of £194,804. That is admitting it to be allowable to put the two three-phase lines or six wires on one pole. Seeing that the wires must be from 7 to 10 ft. apart, it is very doubtful if it would not be better to erect two sets of poles with three wires only each, and that would increase the cost very much. It would also minimise breakdowns in the case of a pole going with the twin circuit. Taking, however, that the line would be put up for £194,804, the interest at 4 per cent. alone would account for £7,792 per annum. Then we have to consider the loss on the step up transformers and line. This would be about 7½ per cent. Running wages at Collie would be 5 per cent. dearer than at Perth, and the station costs would be probably 2½ per cent. to 3 per cent. more owing to higher cost of labor, more freight and water conservation. The upkeep of the transmission line would run into a large figure, and, taken altogether, the saving at 25 per cent. load factor would certainly vanish. As the load factor went up figures would be better, but unless the load were well equalised the loss on line would become greater. Again, the advantages of electrification of railways has been found not to be so great as at first thought, and it is now accepted that it is not desirable to scrap all existing plant unless it is necessary to recall traffic lost by competition and to avoid a large capital expenditure for land, buildings and suchlike.

MR. LESLIE said he would also like to express his appreciation of the time and trouble the author had expended in the preparation of this paper. He had brought into view a good many factors which were worthy of much further investigation. At present he was somewhat disappointed at the results arrived at

by him. Broadly stated, they were, on a 100 mile transmission scheme, with coal at the pit mouth—certainly not of high calorific value, but costing only 4s. per ton—to provide current, the nett cost of which comes out as high as eight-tenths of a penny per unit. Of course, it is obvious that about one-sixth of this cost is to provide interest on existing plants, which are set down at £800,000, and in regard to which he had made no allowance for writing off, but would continue to be a perpetual charge. Any scheme was doomed to failure which was expected to carry such a large proportion of unremunerative capital which, as the author pointed out in the second last paragraph of his paper would become an even more dominating influence for evil twenty years hence than in the scheme he had just put forward to-day. The author had only allowed 3 per cent. for depreciation and obsolescence; he thought depreciation alone might well amount to that figure, and instead of depreciation it should be set out as a sinking fund. As regards obsolescence, he believed that it had far exceeded that figure in the past, and that no man could reasonably forecast what it would amount to in the future. It would probably amount to as much in the future as in the past. The author put the capital required at £1,766,900, the total of which he expended on works. But treating the proposition as a business one, a private company would not lay down such a plant without a fair margin of additional working capital. Not only would provision be made to operate the plant for a time at a loss until the people were educated to the full and free use of the current and gathered in as consumers, but large stocks of stores, spare parts, coal, etc., had to be purchased in advance, and the operating expenses of the station had to be met for some time before the revenue commenced to flow in. The author does not make it quite clear whether he means total or only partial conversion of the railways to electricity within the area served; as he exempts certain trains, he was inclined to think that he meant partial conversion only. Partial conversion had never yet been a success wherever it had been introduced. Total conversion or no conversion should be the rule. He should also like to ask the author why he proposed to supply the railways with two-fifths of the total output at 25 per cent. less than it costs to produce. This was a very weak spot in the proposition. Selling the *surplus* down to cost, or even a fraction below, may be good business, but to deliberately set out to supply two-fifths of the total output at 25 per cent. below cost is not only courting certain disaster, but is unfair to the other consumers. As set out, the financial success of his scheme depends almost entirely on his forecast of the amount of current to be required for lighting, as there, on only one-tenth of the output, he requires to get a quarter of his revenue. If his estimate of lighting requirements was not reached

and the other selling rates remained constant, to secure twenty-five per cent. of the required revenue the price of the current for lighting might well have to be raised as high as to defeat its own end.

Mr. Broadbent said that no doubt most engineers in W.A. had from time to time given more than a passing thought as to the feasibility of this scheme. On many occasions he had plotted it out and could never convince himself that the project would warrant realisation. The electrical and mechanical difficulties were not insurmountable, as many transmission lines of greater length were at present in operation, but no matter how alluring these schemes appeared to be at first glance, they must stand the closest investigation from a commercial point of view. This particular problem was whether it was cheaper to convey coal by rail or electricity by wires. The author said "the cables would traverse a route close to the Bunbury line," therefore the line would be over 100 miles, Collie townsite being 124, Collie Burn 129, and Collie Cardiff 131, so that he thought his figures should be altered to a line of 125 miles. Not only would the number of miles be increased, but the section of the copper would require to be enlarged or the line losses increased: say the latter. The total losses in the step up and step down transformers and the transmission line would be 10.66 per cent. This would reduce the fuel haulage by 90,000 tons—10.66 per cent.=80,406 at 6s. 5½d., freight (1s. 3d. terminal charges and ½d. per mile) £25,964. The cost of the step up and step down transformers, 42,336 k.w. at £2=£84,672, and 125 miles of transmission line at £1,549=£193,625, or a total of £278,297. Taking the author's standing charges of 8½ per cent. means an annual charge of £23,655, to which must be added £1,600 for way leave charges, bringing the total annual charges to £25,255, or showing an actual profit over coal haulage of £709 a year. We are told that we could get coal at Collie for 4s. per ton. It might be possible at the pit's mouth to get it at 4s. per ton, but it must be taken into consideration that coal in a truck would not be moved unless a minimum of 1s. 3d. per ton was paid for haulage not exceeding five miles, and ½d. per mile afterwards. If this rate was insisted on then an additional expenditure of £5,625 per annum would have to be added to the transmission costs, making the total £30,880, as against train haulage of £25,964, showing an actual loss of £4,916. It might be said that some of the coal could be used direct from the mine, but as no one mine could supply the demand, a large amount of haulage would be required. Handling the coal from the trucks could be done just as economically wherever the site. There were many points on which discussion could advantageously be indulged in. First, as regards cost of erecting such a plant at Collie as against Perth or Fremantle; cost of stores and labor as against Perth or Fremantle; the available water for condensing

at Collie ; the probability of being able to purchase 90,000 tons of small coal at 4s. per ton. He did not think any coal merchant would enter into a contract for that coal—not even in ten or fifteen years—hence that would mean larger coal at a higher price. They could always have a call on some kinds of fuel, and could probably get imported coal at a different price but at an extra calorific value. Extra boiler power to pick up sudden loads, by not having imported coal available. Collie coal was not very good at picking up. Extra boiler power would be required to pick up or some method of forced draught. Loss of £25,964 revenue to Railway Department. Terminal charge of 1s. 3d. would have to be rescinded to get coal anywhere near 4s. So that on the most optimistic figures the scheme would not pay, even when the output reached 60,000,000 units.

Mr. Crocker (communicated) : Mr. Edmiston's paper appeals to one principally as a summary of the general principles applying to an electric transmission from Collie to Perth. The proposal has been brought up at various times in the past, and at one time it was suggested that Collie power should be transmitted to the Kalgoorlie mines. Assuming that Mr. Edmiston's estimates of capital cost are right, it seems to me that he has considerably under-estimated the production cost in several items. Four per cent. interest charge seems too low, when even public loans frequently have to pay 4½ per cent. The minimum allowed for such a purpose should be 5 per cent. The same applies to depreciation, under which head I assume he includes sinking fund. Five per cent. is generally considered the lowest allowance for a general depreciation fund, and many authorities insist even on a higher. As near evidence of obsolescence we have the greater portions of the plants of the Perth Gas and Tramways companies, which, owing to improvements and new proposals, necessitated by the progress of events, have become practically obsolete in considerably less than twenty years. The same thing has occurred in many places. I fail also to see how the cost of " superintendence, attendance on consumers, accounting and collecting of revenue " for sixteen districts can be covered by £38 9s. 6d. per day, especially as this sum appears also to cover substation and transmission line operation, inspection and maintenance. Increase in these items alone would show a considerable increase in the estimated cost per unit sold. Mr. Edmiston draws no comparison between the generating costs with plants at Collie and at Perth. This is the point on which the whole consideration hinges. The only saving in generating at Collie would be in the cost of fuel, which he takes at 4s., and which is, I believe, 12s. in Perth. The difference of 8s. on 90,000 tons per annum would give the savings as £36,000, and as it would be necessary to produce about 5,000 units less in Perth owing to saving of transmission losses, the real saving in fuel

cost would be about £33,000 per year. Against this saving would be set off the cost of the long distance transmission, which would amount to at least £36,000, made up as follows :—

Line £154,900 at 5 per cent. interest and 3 per depreciation	£12,392
Transformers at two ends, 42,336 k.w. at £2 at 5 per cent. interest and 5 per cent. depreciation	8,467
Upkeep and renewals on above items at 1½ per cent.	5,380
Right of way, etc.	1,600
Transmission and sub-station operating expenses, 360 days at £30	10,800
	£36,839

That is, for the saving of £33,000 per year in fuel there would be expended some £36,000 in transmission costs. It would appear there are no advantages in generating power at Collie for transmission to Perth under the conditions Mr. Edmiston assumes, as it can probably be generated as cheaply by a large plant in the metropolitan area and by gas or oil plants in the smaller places which might be served along the route of the transmission line. It is agreed that unless there is a material gain it is preferable to avoid the uncertainties and "strange phenomena peculiar to high tension transmission." It is evident that the more economical prime movers become in fuel consumption the less margin there will be for transmission from coal fields, because the amount of fuel to be transported will become less. There has been a vast improvement made in the last ten years in fuel consumption, and the next ten may show an even greater change.

Mr. Edmiston said he was grateful to members for the very kind reception they had given to his paper and for the very patient hearing they had extended to it as well. He was pleased to learn that some of the members were sufficiently interested as to promise some discussion on the paper. He should be very glad indeed to hear that. He might say that he wrote this paper in much shorter time than he should have liked to have had for it, though he had known that he was going to write a paper for the last six months or so. He had prepared a paper, at least he had prepared a skeleton of a paper, which he thought would be rather interesting, but, unfortunately for him, another member of their Institution dealt with the whole subject and in a manner which he thought much more able than he could have done, so he had to change his ground and seek another sphere. This subject of the Collie coal business was one which had always

interested him. He had shown them in about two figures what it was going to cost to produce electricity in Perth—something like ¼d. a unit the transmission line was going to cost. He had put that down at £100,000. He found that it was a good bit more. Calculate what it was going to cost for a 10,000,000 units of electricity per annum. The interest on transmission line of £100,000 would eat up all their coal—there would be no profit left. They had only three-eighths of a penny to make their profit out of and the interest on the line would come to something like three-eighths of a penny. That always knocked them clean out. He thought they must realise to-night whether he was right or wrong, that was in the way the subject had to be treated. As he had pointed out to them in his remarks, the question of the cost of this energy was not everything. It was the question of bringing about a finer and cleaner civilisation. There was one feature about such a transmission and that was this, when they had reached a point when the transmission system would equal or beat the other system, then they had arrived at a position when it must be adopted. Another important feature was this: that the cost of fuel at the seat of energy would be something like one-third of what it could possibly be here, therefore their surplus power could be sold at a very much smaller figure. If their coal was going to cost three times what it would cost in Collie; if they decided to sell their surplus power at the cost of fuel and having their plant in Perth, it must necessarily be three times the cost of electricity if it was produced in Collie. They could never have the electric age until they made the very best out of what nature had provided them with. Replying to the discussion on the general matter of the paper, I find that this hinges mostly around the question of the comparative cost of supplying electricity direct from Collie and indirectly from Perth. The very natural method of balancing the transmission losses against the coal transportation cost is generally resorted to. Mr. Crocker points out that no comparison is made between the generating costs with plants at Collie and at Perth. As a matter of fact, I had come to the conclusion that, at any rate, it would not cost more to supply the power from Collie than from Perth, and there my interest in this phrase of the problem terminated. The proposal outlined in the paper is more than that of a mere transmission from Collie to Perth. The proposal outlines a scheme that would not only supply Perth, but would serve the greater portion of the south-western corner of the State as well, including the Bunbury Railway. The writer calculates that no great and sudden development can take place unless the price of supply is brought to below one penny per unit, and that in order to consummate this desirable end an output of not less than 60 million units must find an outlet. Perth alone could probably not take so large a supply even at .8 pence per

unit, but it is calculated that with the additional area provided around the transmission lines from Collie a sufficient demand could be established. In this way it is assumed that an additional demand for fifteen or sixteen million units could be found, including that from the coal mines and the railways. This phase of the problem is not specifically set out, but neither is the proposal set out in this respect so far as any other part of the scheme is concerned. Mr. Leslie takes exception to the rate of interest, but it must be admitted that he does not use this to discuss the relative merits of Perth and Collie as centres of production. Mr. Crocker considers the rate of interest and allowance for depreciation too low. Regarding Mr. Dowson's opinion that the load factor of 35 per cent. adopted by me is too high, and that 25 per cent. is more probable, I may say that if he could demonstrate his opinion that alone would be sufficient to end all serious discussion as to the practicability of such a proposal. Since hearing the discussion I have been able to prepare a series of load curves dealing with the five different types of consumers enumerated, namely, lighting, tramways, industrial, railways, and domestic. Examination of the diagrams will disclose that the resultant maximum demand on the supply mains occurs at 5.6 p.m. and a line drawn through the curves at this point indictaes that the aggregate power demanded at that time is as follows :—

Lighting	1,650 k.w.
Tramways	1,070 ,,
Industrial	2,812 ,,
Railways	2,831 ,,
Domestic	8,580 ,,
Total	16,943 k.w.

On an output of 60 million units per annum, a maximum demand of 16,943 k.w. produces a load factor of 40.43 per cent. It must be remembered also that the curves do not represent the daily maximum demand, but the absolute maximum demand at the heaviest period of any year, and that the cause that produces the maximum in one class of load would probably not affect any of the others. The chances of all these different classes of consumers being similarly affected on the same day and hour are remote in the extreme. I think in any case that the 35 per cent. in the estimate is safe enough. Mr. Dowson's view that the estimated coal consumption is too low is not based, as far as I can see, on good evidence. Unless the examples he quotes coincide in all respects with the one under discussion the comparison would be of little value. The coal consumption will vary with the conditions under which the output is produced—the load factor, the magnitude of the output, the steaming value of the coal, the inherent efficiency of the appliances, and many other circumstances. In my opinion the most serious doubt as to the practicability of the Collie project will be found in the practicability of

electrifying the railways. In all probability it has yet to be demonstrated that our main lines can be economically operated in this way. Mr. Dowson also expresses some doubt about securing sufficient outlet for fifteen million units for tramways and industrial use. I think there can be no doubt that five million units will be needed for tramways within the year 1914. I feel sure the Railway Workshops require about one million units, or must soon need that quantity. The Collie coal mines could probably use five millions; half a dozen flour mills would take at least two millions. Bush timber mills might be induced to connect up with the supply, but wood working mills and factories would probably use another million. There are several thousand windmills that would find a serviceable assistant in an electric supply, and the Metropolitan and many other water supply authorities would probably consume some power. It is very probable that many small industrial users of power who cannot afford to use electricity at twopence or threepence a unit would be induced to do so at from $\frac{3}{4}$d. to $1\frac{1}{4}$d. per unit. I think that at an average price of a penny per unit ten million units would find a ready outlet for industrial purposes. If I had described the transmission as running parallel with the railway it would have made my intention clearer. It would be a matter for close investigation when dealing with a concrete scheme which would be the more economical method, but at present it would seem that the more direct the route the better. As a matter of fact the 60 million units would not all be transmitted along the main transmission lines. The output for the railway and for the S.W. district, amounting to probably over a quarter of the total, would not have to travel very far. I may say that I adopted the value of 3 per cent. for depreciation and obsolescence as that seems to be what is generally allowed by the great electrical concerns in most countries. The State Government intend to set aside that amount in respect for sinking fund, depreciation, and obsolescence. The average amount provided by the municipal corporations of Great Gritain is about .7 per cent. plus the statutory sinking fund. The British proprietary companies allow on the average $2\frac{1}{2}$ per cent. for depreciation and obsolescence, but nothing for a sinking fund. I believe the theoretical amount for depreciation and obsolescence is 10 per cent. in respect of electrical industries. If we adopted the theoretical 10 per cent. instead of 3 per cent. in this case it would raise the price to the consumer by 61.5 per cent. This would, of course, have a very marked effect on the popularity and on the prospective growth of the concern. This antiquation in turn is due, partly to improvements in economical design, but principally to the fact of appliances soon becoming too small owing to increasing demand, and no kind of improvement is any improvement at all, if it cannot provide against the obsolescence of which it is itself the cause. Mr. Leslie's contention

that any scheme is doomed to failure that is expected to carry such a large proportion of unremunerative capital is not sound in view of the foregoing, and from the fact that probably half the capital expenditure carried by the electrical concerns throughout the world is of that nature. The value of these concerns and the security that they give to investment lies in their potential growth, and when that reaches its limit then a still smaller annual charge will meet the losses due to depreciation, etc. I think Mr. Leslie is on more solid ground when he speaks of the advisability of providing a fair margin of additional working capital to operate the plant at its earlier stages and to provide for stores, etc. However, if the proposition is treated as a business one, as he suggests, care will be experienced that these expenses will not exceed the minimum. In all probability the capital would be expended at a judicious rate per annum and in accordance with a well thought out building programme. In any case, if such a scheme were adopted two-thirds of the output would at once be assured, counting on the railways and what is already being used. Mr. Leslie's contention is perfectly sound, however, but I think not of a very serious nature. The same critic points out that I do not make it quite clear whether I mean total or partial conversion of the railways to electricity. The fact that I exempted certain railway traffic is not to be taken as having any significance in that respect, beyond the fact that I had no means, at the time, of estimating this part of the traffic. Mr. Leslie asks me why I propose to supply the railways with two-fifths of the total output at 25 per cent. less than it costs to produce ; it is not only courting certain disaster, but is unfair to the rest of the consumers. The cost of producing power for any purpose depends, all other things being equal, upon the amount produced, and the reuglarity of the rate at which it is produced. Capital charges, including upkeep and renewal of plant, represent three-quarters of the total average cost to supply in the Collie scheme. This is equal to .60d. per unit. The short hour consumer is therefore entitled to pay 3.6d. on account of standing charges, while the long hour consumer can only reasonably be charged .60d. That is, of course, an extreme case. Take the case of the lighting output, as dealt with in the paper. Lighting accounts for one-fifth of the total capital cost, but there is £665,000 provided for distributing mains for which the lighting is responsible for by far the largest share—probably not less than half. For this I will debit the lighting with another £250,000. This comes to .937d. per unit of the lighting output. Again, not less than one-third of the total distributing cost is chargeable to the lighting alone. These distribution charges have been placed under the two headings "Management and Administration" and "Distribution," amounting to £19,000. One-third of

this amount produces a cost of .2533d. per unit for the lighting. Therefore the total cost for lighting is roughly :—

Average capital charge, including upkeep and renewals	.6050d.
Addition capital charge for mains	.9370d.
Distributing cost (wages), etc.	.2533d.
Fuel as per estimate	.0720d.
Engine House, stores	.0160d.
,, ,, wages	.0240d.
Right of way	.0064d.
	1.9137d.

This comes to 1.9137d., and the output is only one-fourth of the railway output, and something would have to be added on that account also. On a similar basis of calculation it is found that the power for the railway does not cost more than .568d. In fact, there is little comparison in the relative cost of supplying the two, and similarly it will be found that the "cost to supply" the tramways, the industrial power and domestic output varies according to the conditions under which production and distribution are effected. In any case, if Mr. Leslie has it in his mind to pool the costs and to charge all consumers alike he would be likely to have a flourishing business in the lighting department, but the tramway, industrial and other loads would be sure to decline. Mr. Crocker's reference to the uncertainties and to the strange phenomena peculiar to high tension transmission ceases to have the significance that it merited, with probable justice, six years ago. Since that time conditions have altered greatly and the transmission lines in modern installations have ceased to form the weakest link in the system. The latest form of insulator (suspension type) has raised the permissible voltage over 100 per cent., and it has yet to be discovered how much higher. That and the development of the so-called cellular system of electrolytic lighting discharge, together with vastly improved means of suppressing the power-arc, has practically eliminated 90 per cent. of the troubles hitherto experienecd. The earth wire system of dealing with lighting has itself greatly assisted in the matter, and elimination of high tension switching has practically removed one of the greatest sources of breakdown. In the scheme set out coronal loss has been guarded against in the lines by an interaxial spacing of 9 ft. 6 in., and the resultant self-induction loss in the conductors allowed for. The remaining troubles are purely mechanical and not likely to be serious in Western Australia. The worst difficulty may be occasional high wind storms, combined with the great surface presented by the conductors when heavily laden with ice. Lightning storms of any great intensity are not experienced here, nor any of the severe conditions mentioned.

In any case, and in spite of the severe conditions under which these transmissions have to be operated, in America at least, the appliances have been brought to such a surprising state of perfection that guarantees, for continuity and regulation of the supply, such as would stagger our local managers, are common in that country. Mr. Broadbent's doubts about getting coal at 4s. per ton may be well founded. I had assumed that the scheme being a national undertaking the State would take care to provide itself with a national coal mine. I understand that the average cost of putting coal on trucks is something less than 4s. per ton. Even then, as Mr. Broadbent points out, it might cost something more to deliver it in the bunkers. His query about a water supply is perhaps also to the point, and this would, of course, require investigation, but I am certain that, whatever the result, that alone would have very little influence with the matter. Mr. Broadbent's economies are not so sound when he points out the loss due to the non-haulage of the coal to Perth. The economist would, I believe, put that down as a distinct gain. In any case, the growing demand for railway transport would soon find an avenue of use for the rolling stock that would, in this way, be liberated.

EXTENSION OF THE BUNBURY BREAKWATER.

(By A. M. Hutchinson.)

It has fallen to the lot of comparatively few members of the profession to be engaged directly on the construction of Harbor works in this State, and the paper I have chosen will, therefore, I trust, contain some matters of interest to members, and may perhaps be of some value to the Institution, relating, as it does, to the quarrying, transportation and deposition of large stone for breakwaters.

The subject matter is a brief description of the harbor, quarries and the methods adopted in the construction of the Bunbury breakwater extension. I am indebted to the Engineer-in-Chief, by whose kind permission I have written the paper, and from whom I have been able to obtain drawings, and to Mr. Carrington, who was Resident Engineer during the contract, and to whom I was assistant on the supervision. A short description of Bunbury and its present harbor is necessary, in order to grasp the reason for a breakwater.

Bunbury has not naturally a harbor, but there is an indenta-iton in the coast known as Koombana Bay, at the south of which an estuary—Leschenault Estuary—has an outlet to the sea. Half a mile north-west is Casuarina Point, being the western point of the indentation. Bunbury lies to a certain extent between this point and the Estuary, and it will thus be seen that what harbor there was faced north, and was therefore open to north-west and partly so to westerly gales—these naturally causing the heaviest seas on the west coast.

A jetty was run out some fifty years ago for 1,400 feet in a north-easterly direction, and this early improvement has some items of interest. Some of the jarrah piles are still good and most of the headstocks are still solid. A feature of this jetty is that all the timber and piles were square hewn, and trenails were used in place of bolts. With the advent of goldmining and the development of timber and other industries shipping increased, and the original jetty was lengthened. Though exposed to the full force of nor'-west gales, it was to some extent sheltered from direct westerly seas by a reef running out north from Casuarina Point.

In 1896 it was decided to construct a breakwater from this Point, curving gradually from 12° north-east to 54° north-east for a length of 3,215 feet, using this reef as a foundation, and

thus giving ample shelter to the shipping moored at the jetty and in the Bay. This was completed in 1899, and was the alternative of two schemes, the other being the Inner Harbor scheme, at a cost of £420,000.

Expansion in trade necessitated further extensions to the jetty, and in 1906 the jetty head had reached a point again at which the full force of the westerly seas was felt, causing much inconvenience in mooring large vessels and damage to jetty and gear. It was a common occurrence for trucks to be thrown off the jetty roads by ships bumping against the fenders.

It was therefore proposed to extend the breakwater a further 800 ft., and in April, 1906, the contract was let for this extension. The extension was designed by Mr. Dillon Bell, who also drew up the specification, and was carried out by Messrs. Barry and McLaughlin, under Mr. Carrington's supervision. The quantity of stone estimated to be required was 228,000 cubic yards, or 320,000 tons in position based on the constant of 1.41 tons to the yard *in situ*. This stone had to be obtained from a basalt reef about a mile from the existing breakwater head, or alternatively, from the Roelands granite quarries, situated 16 miles from Bunbury, near the Perth-Bunbury railway. As the original stone had been obtained from these quarries, and the basalt reef had never been opened up, the contractors decided to obtain their stone from Roelands. This meant the haulage of the estimated quantity of 320,000 tons of stone over 17 miles of railway. For this purpose 136 stone trucks of special design, which had been used at Fremantle on the moles and on other works, were again brought into requisition. Two locomotives were required, one to haul the stone from the quarries to Roelands Station on the Government line, where the railway department picked up the train load and hauled it into the Bunbury yard, the other to take the rake out of the Bunbury station yard to the jetty head, and do the necessary shunting for tipping.

The Roelands granite quarries were opened and worked for the construction of the original breakwater, and all the plant was left there and was available to the contractors for the extension. The weight of this granite in the solid is 2 tons to the cu. yard. Three ten-ton cranes and one thirty-ton Ransome crane were used at the quarries, and one thirty-ton Ransome crane was used for building the parapet wall on the mole. Rand compressed air drills were used in quarrying, the power being supplied by a 40 H.P. boiler and compressor, reticulation pipes being run over the face of the quarry.

The original breakwater had been run out for a distance of 1,500 feet, 16 feet above L.M.W., with a cross section as follows:— Top width increasing from 25 ft. at the 00 to 57 ft. at 1,500 ft.;

slopes 1½ to 1 and no parapet; from 1,500 to 3,215 ft., top width 57 ft., slopes 1½ to 1 above water on ocean side and 1¼ to 1 on harbor side, and having a parapet wall 12 ft. high with a sea slope of 1½ to 1 above water, the ocean slopes being approximately 4 to 1 below water, the parapet wall having a rough inside face battered 1 in 6. Owing to the heavy seas drawing down the sea slopes and bringing down the parapet on the original work, the design of the extension was altered, and the width at the top of the breakwater was increased to 75 ft. from 3,215 ft. to 3,800 ft., then gradually increasing to 92 ft. at centre of round head at 3,969 ft., the height above L.W. being the same as at commencement of contract, and the cross section of the parapet being also similar. The centre line was curved, the radius being 2,800 ft.

The section of the extension, however, left a berm of 18 ft. on the sea side, so that should the heavier waves dislodge any stone the berm would only be first drawn down, with every probability of leaving the parapet wall safe. As a matter of fact, no stone of any consequence has been dislodged on the sea face by wave action since the completion of the work—that is five years ago.

The stone required was divided into 1st, 2nd, 3rd and 4th classes. First class stone was applied to stones ranging between 8 and 15 tons; second class, between 3 and 8 tons; third class, from 5 cwt. to 3 tons; fourth class, from ½ cwt. to 5 cwt.

The breakwater section (disregarding the parapet) was divided into three parts—the outside face, or sea slope, consisting of first and second class stone in the proportion of 75 per cent. of first class and 25 per cent. of second; the middle portion, or main body, consisting of a mixture of second, third and fourth class stone, proportioned so as to form a fairly solid body (the small stone filling the interstices), and the harbor face consisting of second class stone. The extension, when completed, was to be approximately made up of 25 per cent. of first, 30 per cent. of second, 30 per cent. of third, and 15 per cent. of fourth class stone.

The large percentage of first class stone, averaging 10 tons—that is a cubic measurement of 135 cubic feet, or 5 cubic yards—on the sea side, it was expected would break the force of the waves as they rolled up. The middle part gave the necessary weight to the structure, and the harbor side was considered to be well protected by stone averaging 5 tons each. Stone tipping began in July, 1906. The middle portion was run out first for a distance of 200 ft., by the use of the end tip and side tip jarrah trucks. These tip trucks, or trucks of a similar construction, are used on most engineering works, so I will not specially refer to them, except to say that the end tip 4-wheel trucks carried 2nd,

3rd and 4th classes, and that the side tip trucks (4 and 6-wheel) carried all classes, the 6-wheel carrying the 1st class stone, the fastenings being hasp and spigot with cotters.

The method of tipping with end tip trucks was as follows :—There were two loops off the main road on the breakwater. The loaded rake was drawn on to one, the locomotive uncoupling and running round, picked up, say, six trucks and pushed them down on the main line to within 100 ft. of the tip. A jarrah buffer was fixed to the rails at the tip head, the rails having a slight falling grade towards the end. When within about 100 ft. of the tip, the engine was stopped, and the first truck was uncoupled and allowed to run down to the buffer, gaining momentum as it travelled. The sudden stoppage at the buffer gave the necessary kick upwards to the tilting floor, when the hasps were released, and the stone slid forward into the water. The truck was then hooked up to the loaded rake with a wire rope and drawn back. As the engine and loaded trucks cleared the points, the switch was thrown over, and the empty truck was shunted on to the first loop, and the second truck dealt with in the same manner.

The side tip trucks, which carried the largest stone, were placed exactly where required by the locomotive, and if the stone was properly loaded, were easily tipped when the cotter pins were drawn. It was, however, generally necessary to chain a side tip by the wheels to the rails when tipping a 12 or 15 ton stone.

When the middle portion had been completed to about 150 ft. the sea slope was brought up to within 50 ft. of the head. This was nearly all tipped with side tip trucks, the road being pushed over as far as was safe. As it was often a difficult matter to keep the rails fairly level, a reasonable quantity of spalls and quarry rubbish was used on the breakwater for packing roads.

The harbor slope was allowed to remain unfinished until nearly all the other stone was tipped. When the head was 200 ft. out it was noticed that the sand travel, which had made rapid progress along the sea slope of the original breakwater, was beginning to follow the extension. It was, therefore, decided to keep the sea slope within a few feet of the head of the middle portion. This sand travel has made a difference of from 10 to 16 ft. in depth along the sea slope of the mole—that is, where there was originally 20 to 26 ft. of water, there is now for some considerable distance out about 10 ft. only. This shoaling, however, adds considerably to the stability of the work. Sand travel forms a very interesting subject and has been thrashed out in various other places besides Bunbury. An examination of the mouths of the various streams on the western coast shows that in all cases where there is no rock on the beach the streams,

after making their way through the sand hills, generally have a northward course to their outlet to the ocean, thus clearly showing that the sand bars which are formed at the mouth are due to sand travel from the south. At Bunbury investigations were made in the summer of 1902-3, but no indications were found of a regular or permanent current from the south, and therefore the direct cause might possibly be put down to the winds, the prevailing ones being southerly all the summer.

Mr. Ridgway, in his paper on "Coastal Erosion" before this Institute in June, 1912, dealt very fully and ably with the subject of littoral drift, and stated two theories—one, advaneed by Sir John Coode, "that the direction of the movement of shingle along any coast is similar to the direction of the prevailing winds," the other, advocated by Messrs Wheeler, Douglas, and others, "that the travel of drift is directly influenced by the current set up by the flood tide." In the case of the sand travel at Bunbury the writer is inclined to think that the former theory applies. The current set up by the flood tide would probably be from south to north, though the ordinary rise and fall of tide is comparatively small.

The accumulation along the mole on the sea side is no doubt due to the same cause, and it is reasonable to suppose that the accumulation inside the mole has been caused by the wash around the head of the mole, the position of the head of the mole causing the waves to swing round, altering their direction from east to south. The flood waters of the estuary and rivers are also a factor in the inside accumulation, probably accounting for the shape of the sand drift, though apparently having very little scour effect.

To keep up an output necessary to complete the work within the contract time, it was estimated that 500 tons of stone per day had to be despatched from Roelands quarry. This rate was, however, not sustained, though an average of about 350 tons per day was sent forward in two rakes of about 40 trucks each. The number of trucks available made three rakes, so that there was always one rake in the quarry, the empty trucks being returned as soon as they were unloaded. The rakes were divided as nearly as possible into a proportionate number of end tip and side tip trucks, so that the percentages of stone required were tipped every day. All loaded trucks were weighed over a railway department weighbridge at Roelands, and the weights were recorded and stone classed, and it was therefore possible to tell at any time the percentage of first, second, third and fourth class stone despatched, and the tipping was arranged accordingly.

During the first few months there was great difficulty in obtaining large stone by ordinary methods of rock drilling and shooting, *i.e.*, by using small charges of explosives and working over the face of the quarry. First-class stone was required for the sea slope of the extension, as the hearting or centre was being pushed out very rapidly.

In April, 1907, the contractors after consultation with the resident engineer decided to try a large shot. The conditions of the quarry then lent itself to an experiment of this nature. A tunnel approximately 4 ft. x 3 ft. was driven 70 ft. into the granite on the floor of the quarry, with a drive each way at the head, the east drive being 31 ft. and the west 17 ft. Approximately 5 tons of powder and 20 cases of gelignite were deposited in the drives. The adit openings were concreted and the tunnel rammed with spalls and the shot was fired on April 18th, 1907. Besides making arrangements to fire by electric ignition, the contractors laid two fuses, as well as the wires. The battery as supplied was not strong enough to spark from the top of the quarry face, the fuse firing the shot. Before firing, the author made an approximate measurement of the probable stone that would be moved, and estimated that about 60,000 tons would be shattered and thrown out. The shot was a complete success—the force of the explosion following the line of least resistance, travelled up the diorite wall, lifted the granite, throwing it outwards, when it slid quietly down on to the quarry floor.

The report was comparatively silent, settlers three miles away not hearing it, many shots of a few plugs of dynamite being louder; neither did the stone fly to any great extent.

The fumes were very strong and enveloped the quarries for probably an hour after the shot had been fired. This is, I believe, one of the largest quarry explosions in Australia, and the only one in Western Australia, and the results were excellent. A plentiful supply of large stone up to 400 tons in weight was available—the large ones, of course, had to be drilled, but a great number of stones of about 10 tons each were immediately available for transfer to the breakwater tip. Previous to this shot, the rate at which the stone was being obtained was not coming up to expectations, but afterwards the quantity was materially increased, and some very fine stone up to 15 tons weight was tipped.

With reference to the transport of stone, careful supervision was necessary to keep the percentage of the classes of stone loaded at a certain rate, so that the total quantity tipped on completion would work out to specification.

As the work proceeded the sand travel previously referred to began on the ocean side of the mole and continued to follow up the extension. There was also a large accumulation on the harbor, side which had been increasing every year, and which at that time was being suction dredged. The dredging, however, was not carried out nearer than 200 ft. from the mole, as it was considered that a possible scour might bring down a portion of the extension.

The sand accumulation began to cause some anxiety at the tip, as the hearting of the mole was pushed out and first class stone was difficult to obtain until the large shot. However, it was then possible to keep the sea side slope up to within 50 ft. of the tip head. This was continued then right through the job. The sand, however, reduced the depth of water considerably, and towards the end of the work it was found, from monthly soundings, that the required quantity would fall short of that estimated by over 100,000 tons, which was partly due to the sand accumulation and partly to the constant used in estimating, *i.e.*, 1.41 tons to the yard.

During the winter it was generally rough and considerable difficulty was experienced in obtaining accurate measurements of the toe of the mole in 20 ft. of water with heavy seas running. The method adopted to make sure that the toe was out to the required distance was this : a 6 x 6 Oregon block 3 ft. long, painted red, was used as a buoy, the anchor being an old brake block. The length of the wire rope used was about 12 in. shorter than the depth at low water. The buoys remained nearly perpendicular in calm weather and were placed at the proposed toe of the mole at distances of 50 ft. on each side, and stone was tipped until they were all sunk.

A shallow finding glass was used to investigate the batters and to find if the slopes were uniform. It was a matter of conjecture before the work started as to whether these slopes could be carried out by tipping directly off the trucks, and the general opinion was that barges or punts would have to be brought into requisition, anchored off the mole, and winch gear and ropes used to claw the stone down. However, though tipping was at times difficult and large stones were occasionally deposited in the wrong places, the whole of the slopes were tipped from trucks and finished off with jacks. This work was very dangerous, but no serious accidents occurred on the mole. Occasionally several stones would slide, and the waves were sometimes strong enough to bring down 100 to 200 tons of stone, though no bad washaways occurred during the two winters the work was in progress. The parapet wall was built of first, second and third class stone in the proportions of 67 per cent. of first, 23 per cent. of second, and 10 per cent. of third class, the total quantity being 7,529 tons

over the weighbridge. All the face stones were carefully chosen, the inside face being kept as nearly as possible battered 1 in 6, the stone being placed in position by a 30-ton steam crane.

The average number of men employed at the quarries was about 100, and there were from 8 to 10 men tipping stone.

The author has not been able to obtain data as to costs of the previous work, which were increased considerably by heavy storms and washaways, but the following are the contract rates for the extension and the actual quantities of stone tipped :—

Tendered price per ton in position :

	s.	d.
First class stone	5	3
Second class	4	6
Third class	4	1
Fourth class	4	0

The actual quantities tipped were :

First class	50,972	tons, being	28.7	per cent.	of total.
Second class	45,618	,,	25.7	,,	,,
Third class	53,786	,,	30.3	,,	,,
Fourth class	27,177	,,	15.3	,,	,,
Total	177,553		100		

The number of trucks tipped was 25,603, the length of the extension being 800 ft., and the contract price £59,966 6s. 0d., the cost per lineal foot therefore was £74 19s. 2d., and the actual cost per ton for all stone tipped in the breakwater 6s. 9d. Stone tipping began July 24th, 1906, and the last stone was tipped on April 4th, 1908, the period occupied being 20 months.

With reference to the constant used it was found that for mixed classes 1.41 was too high, and for large stone 1.25 was too low, the mean 1.33 being approximately the correct constant for working on all classes.

Discussion.

Mr. W. Leslie said he had listened to the paper with pleasure, although he did not agree with all of it. He did not think that any of the sand accumulation at the end of the mole was due to flood waters. The sand accumulated there quite as quickly when there were no flood waters coming out of the estuary as when there were. All the rivers on the west coast showed deep water at a very short distance inland, and he did not think any of them were really discharging any sand. Take the Swan River, for instance: there was much deeper water between the coast

line and the base of the hills than at the bar. There was not sufficient discharge of water over the ranges, he thought, to bring down any sand, and, where there was a current, it was possibly over rock. He thought the accumulation of sand at Bunbury was entirely due to travel from the south, and that the drift which was shown inside the head of the breakwater was due to an accumulation at the time of the north-west wind, when the sand had drifted round the end of the mole. The deepest part of the bay was in the centre, shallow water all round it, so he was of the opinion that nothing much could be done round Bunbury in the way of improving the harbor by way of extension of the breakwater. The author had given members very interesting matter with regard to the cost of the construction. He would have liked the author to have mentioned Mr. Newman, to whom he thought was due the credit of the shot and the drives—he arranged it and carried it out.

Mr. E. S. Hume said it appealed to him when the paper was being read that it must be of immense value from a historical standpoint and also from an engineering standpoint, where an engineer required some dtaa to enable him to take out an estimate, or prepare drawings and specifications for such an undertaking. It was also invaluable to a contractor because there he had clearly laid down how much plant he required for such an undertaking and also how long it would take him to carry out such a work, and also the different methods that were adopted on such an occasion, what class of plant was used ; also he could approximately take out the value of such a plant.

Mr. H. Oldham said it was the first time the author had read a paper to the Institution, but he hoped he would not hide his light under a bushel any more. He hoped they would hear some more from him on other subjects of like interest. He would also like to point out to members that they were doubly indebted to Mr. Hutchinson for his paper. They had another paper arranged, but the member who was writing it fell sick and was not able to prepare it. At short notice Mr. Hutchinson had produced this paper. He was sure they would all agree that, though the time was short, he had prepared it in a very able and interesting fashion.

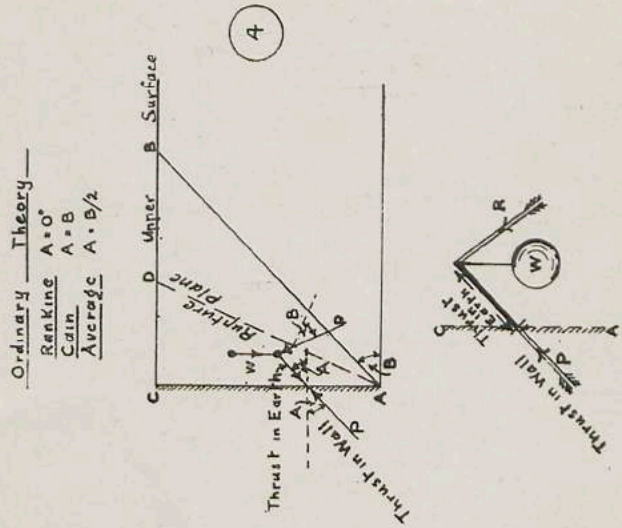
Mr. F. W. Lawson said there was much in the paper that was full of interest. There was a great deal also that he thought Mr. Hutchinson might have given them and that probably he could give them if they asked him. He was not so much interested in what was specified in regard to the outer slope ; probably the specification was quite good in the 4 to 1, but what he was interested to know was actually what it worked out in practice, whether it was found that this slope could have been made steeper, or

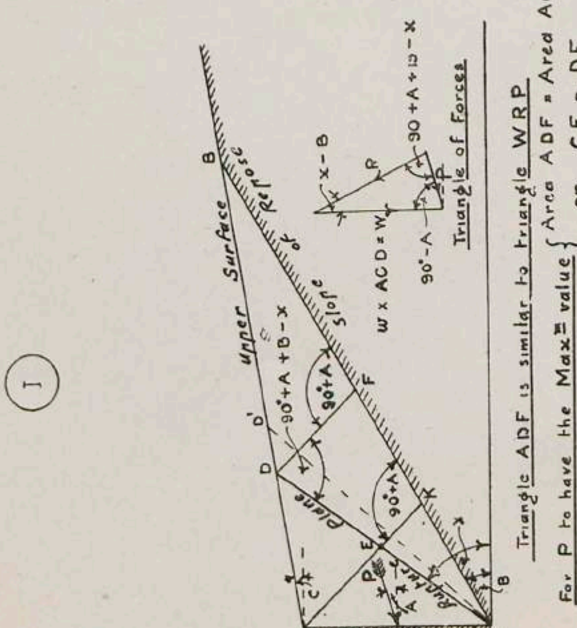
whether it was necessary to make it flatter. The slope appeared to him that it would probably, with the sand travel mentioned, have been slightly decreased. No doubt Mr. Hutchinson had the necessary figures or the necessary observations to tell them what the slope did work out to. The most interesting point in the paper was that of the sand travel. Mr. Hutchinson put this down to the northerly set of the current in this direction, but probably also he could give them a bit of information in connection with this matter by giving them some observations—the velocity of the current and the direction. No doubt these were taken from time to time, probably in connection with the work, and these he thought would practically settle the point as to whether it was the wind or the current. Coming now to the question of blasting. The author gave a very good description of a large shot put in by the contractors to provide the necessary first-class stone. That he should also like to see supplemented by further information as to the relative cost of the two methods of obtaining stone. To his mind he should say the larger shot proved very much more profitable to the contractors and no doubt gave them pretty well all the material that was required. Mr. Hutchinson could go a little further and give something like the approximate prices that the work actually cost. It appeared that the variation in the classes of stone in the tendered prices was so small that in actual work they would find the prices out very considerably. He personally had discussed the matter of tides and the set of the currents along the coasts with a good many masters of vessels, and also he understood the Fisheries Department had taken a series of observations, not so much of the velocity of the current, but particularly in regard to the temperature of the water along the coast, and it had been found that from the Leeuwin up there was a decided drop in the temperature of the water some little distance out from the shore, evidently showing that there was an additional (almost continuous, he might say, as far as the information in his possession went to show) change of water coming up from the South the whole time. This undoubtedly bore out the contention of Mr. Hutchinson that it was the set of the current that had a tendency to make the sand drift in those directions and not the wind. If this was so it had a great influence, not only on the sand drift, but, if it could be proved, he thought it would also show a great dael of reason for the steady and constant temperature along the shores, especially in the southern portion of this State.

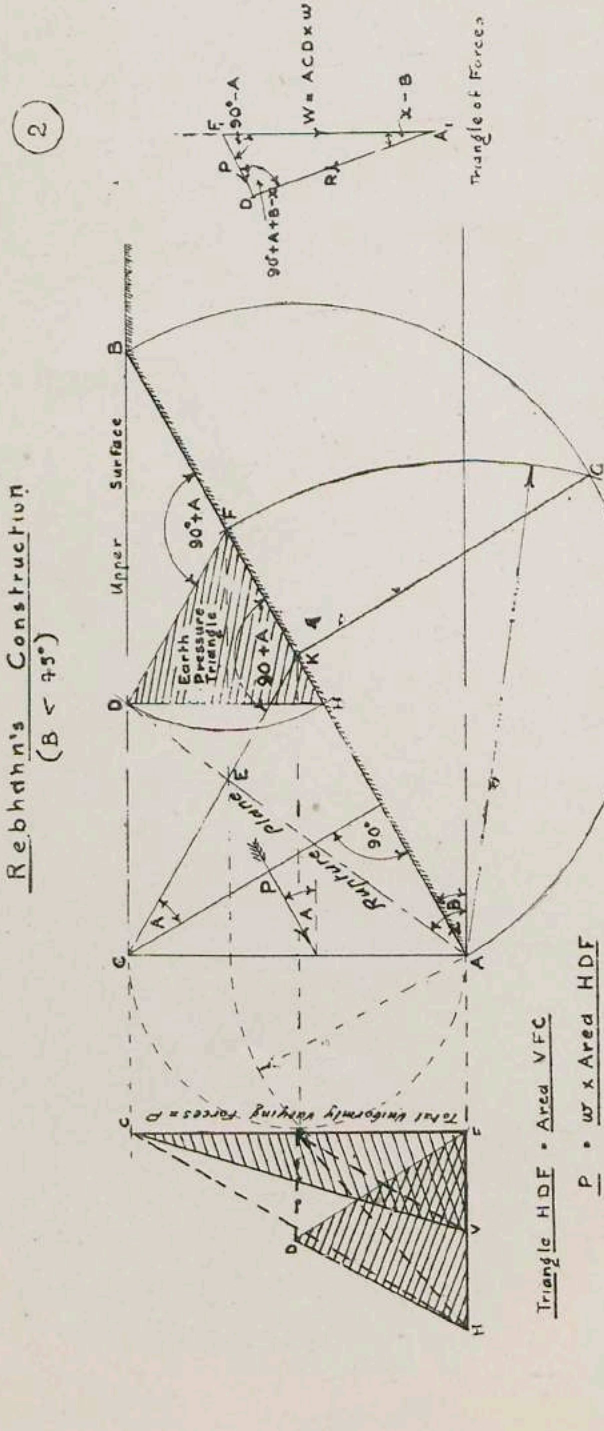
MR. HUTCHINSON, in reply to Mr. Lawson relative to: (1) The question of *Slope*—the slope tipped was not 4 to 1 on the sea face, but 1½ to 1. An extra initial width of 18 ft. 6 in. over and above the actual top width of breakwater was allowed for. If this slope was clawed down by wave action the result would probably be the ultimate profile, *i.e.*, a slope of 4 to 1.

This was, of course, on the assumption that no sand travel would occur and that the depth of water would not be decreased. The sand accumulation has so altered the conditions and the force of the waves is so much broken at a distance from the mole that it is doubtful if a 4 to 1 slope would not be required. In most breakwaters that have been built, according to Harcourt, vol. 1, it has been found by experience that steeper slopes than 4 or 5 to 1 are not stable, and are washed down, that is when the waves are waves of translation. Inside faces of moles where the waves are of oscillation could be built vertically, or at a slope of ½ to 1, though some authorities consider that a vertical wall with a convex curve on the outward face is stable in solid masonry, provided the necessary weight is in the structure. At Plymouth the slope on the surface is 5 to 1 from H.W.M. to 12 ft. below, and in others 8 and even 12 to 1 for 12 ft. to 20 ft. below H.W.M. Under these conditions the wave force is spent before the water reaches the top and the parapet. At Bunbury the flattening of the slope has been left to wave action, thus saving a considerable expense in tipping of the stone. For a 4 to 1 slope staging would have had to be erected to tip the stone or the clawing down would have had to be done from barges anchored off the mole. The original breakwater was tipped, though a considerable amount of flattening of slope was caused by storms, and it is reasonable to assume that the flattening that would occur in rubble tipped roughly 1 or 1½ to 1 would be about 4 or 5 to 1. It is generally considered that there is very little effect from ordinary wave force at a greater depth than 12 ft. below H.W.M. (2) *Sand Travel.*—The Vasse and Capel Rivers, the estuary at Bunbury before the breakwater was built, and the mouth of the Peel Inlet, at Mandurah, have northward courses from the sandhills to the sea. During the progress of the breakwater extension no observations were taken of the ocean currents. From periodical soundings, however, it was seen that the sand travel from the ocean side followed up the extension, *i.e.*, had a South to North travel. The only current observations the author has knowledge of were taken during the surveys of the harbor in the summer of 1902-3, and no very reliable data were obtained. The land and sea breezes caused the floats to drift seaward and landward respectively, and sufficient time was not given to these experiments to ascertain what coastal currents existed. High water is very irregular, depending on the winds and, during summer, when winds off-shore prevail, the water is lowest. With Nor'-West gales the water rises 4 or 5 ft. above ordinary L.W.M., and with Nor'-West winds a strong current sets out of the bay. There is no doubt that surveys and observations carried out over a considerable period, say twelve months, including a summer and winter, would be of incalculable value as data for future works on the South-West Coast. (3) *Comparative Prices of Stone* obtained

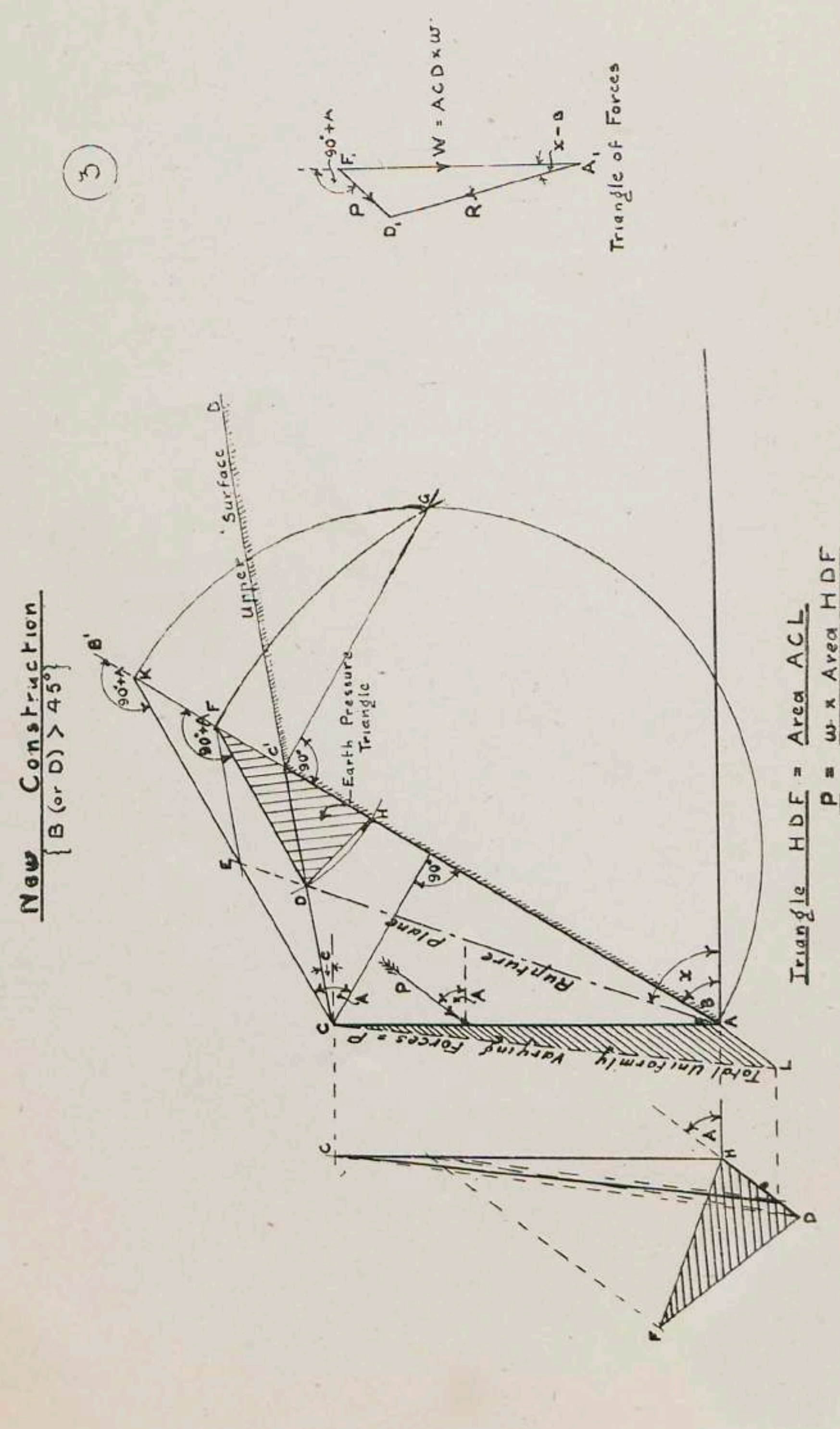
by ordinary methods and large shots.—I regret that from the records kept I could only give an approximate cost of the large shot. The work was a contract one, and though the supervision was thorough as far as working the quarries was concerned, the actual cost per ton of the various classes could hardly be ascertained. The drive of 70 ft. into solid granite was a fairly heavy item, and a considerable quantity of stone had to be broken down afterwards to the maximum 15 tons. The main reason for the large shot was that a great quantity of large stone was urgently required and had to be supplied at short notice. The particularly good conditions under which the shot was fired brought the cost of obtaining large stone down lower than by ordinary rock drilling, as far as could be approximately calculated, but the cost of the smaller stone remained about the same as the cost by ordinary methods.


4
Ordinary Theory
Rankine A = 0°
Cain A = B
Average A = B/2
Upper Surface
Rupture plane
Thrust in Earth
Thrust in Wall
Thrust in Earth
Thrust in Wall

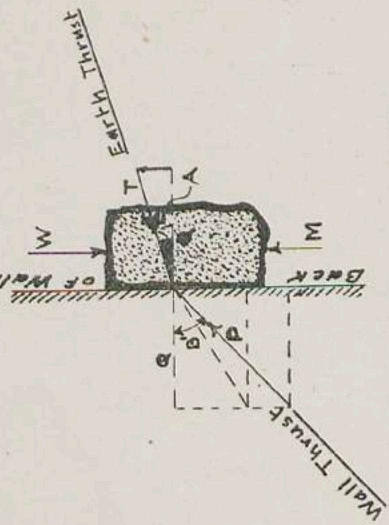

I
Vertical Wall
Upper Surface
Slope of Repose
Rupture Plane
90°+A+B−x
90°+A
90°+A
W x ACD = W
x−B
90+A+B−x
90°−A
Triangle of Forces
Triangle ADF is similar to triangle WRP
For P to have the Max^m value { Area ADF = Area ACD
or, CE = DF



2
Rebhahn's Construction
(B < 75°)
Upper Surface
Earth Pressure Triangle
Rupture plane
W = ACD x w
Triangle of Forces
Total uniformly varying forces = P
Triangle HDF = Area VFC
P = ϖ x Area HDF


3
New Construction
{B (or D) > 45°}
Triangle of Forces
W = ACD × w
90°+A
x-B
Upper Surface
Earth Pressure Triangle
Rupture Plane
Varying Forces = p
Total Uniformly
Triangle HDF = Area ACL
P = w × Area HDF

(6)

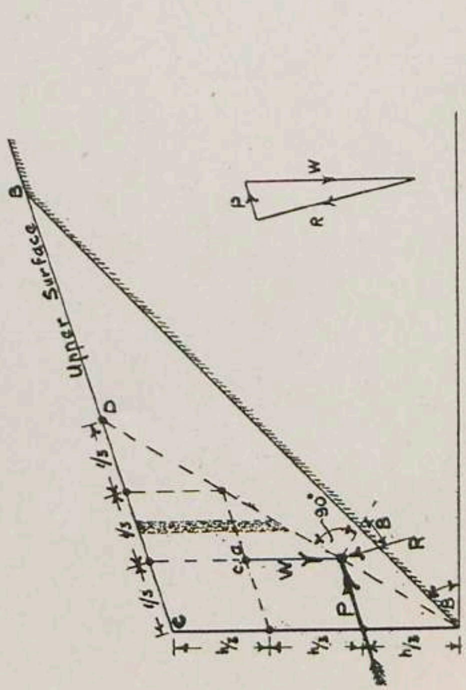


$Q = T \cos A = P \cos B'$

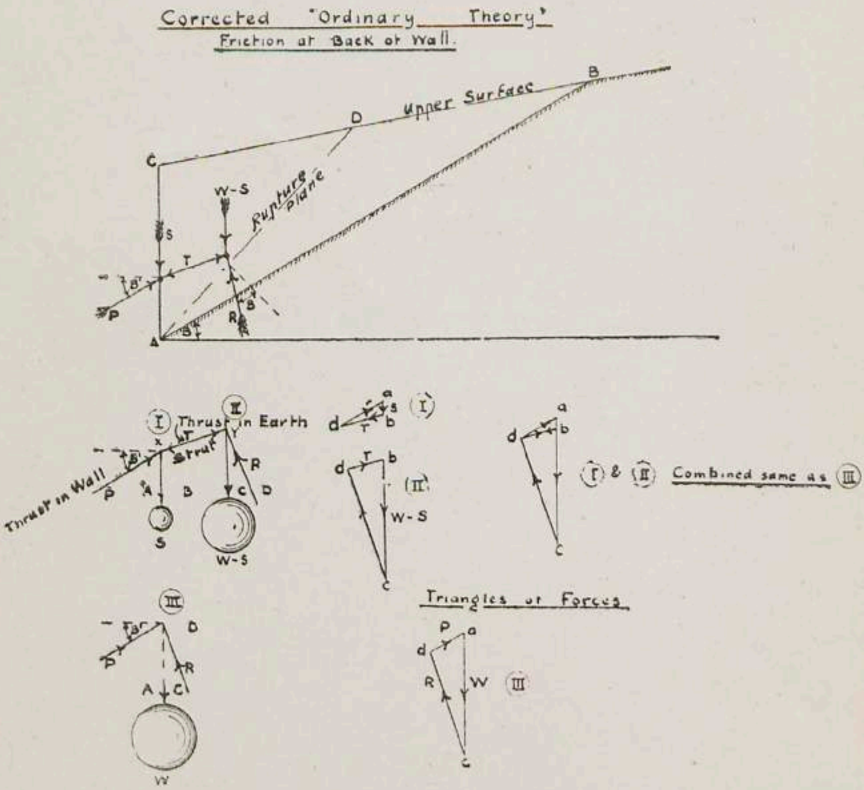
$P \sin B' + M = T \sin A + W$

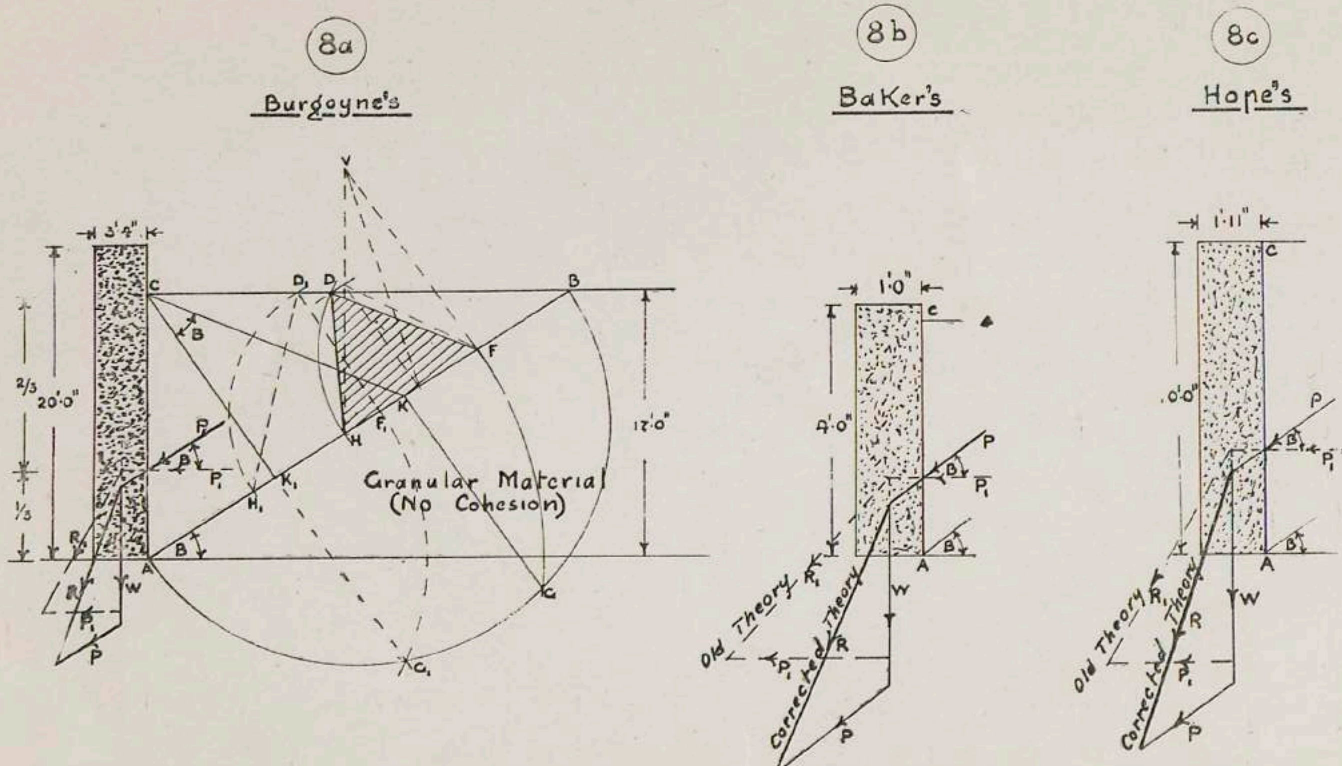
$S = W - M = P \sin B - T \sin A$

(5)

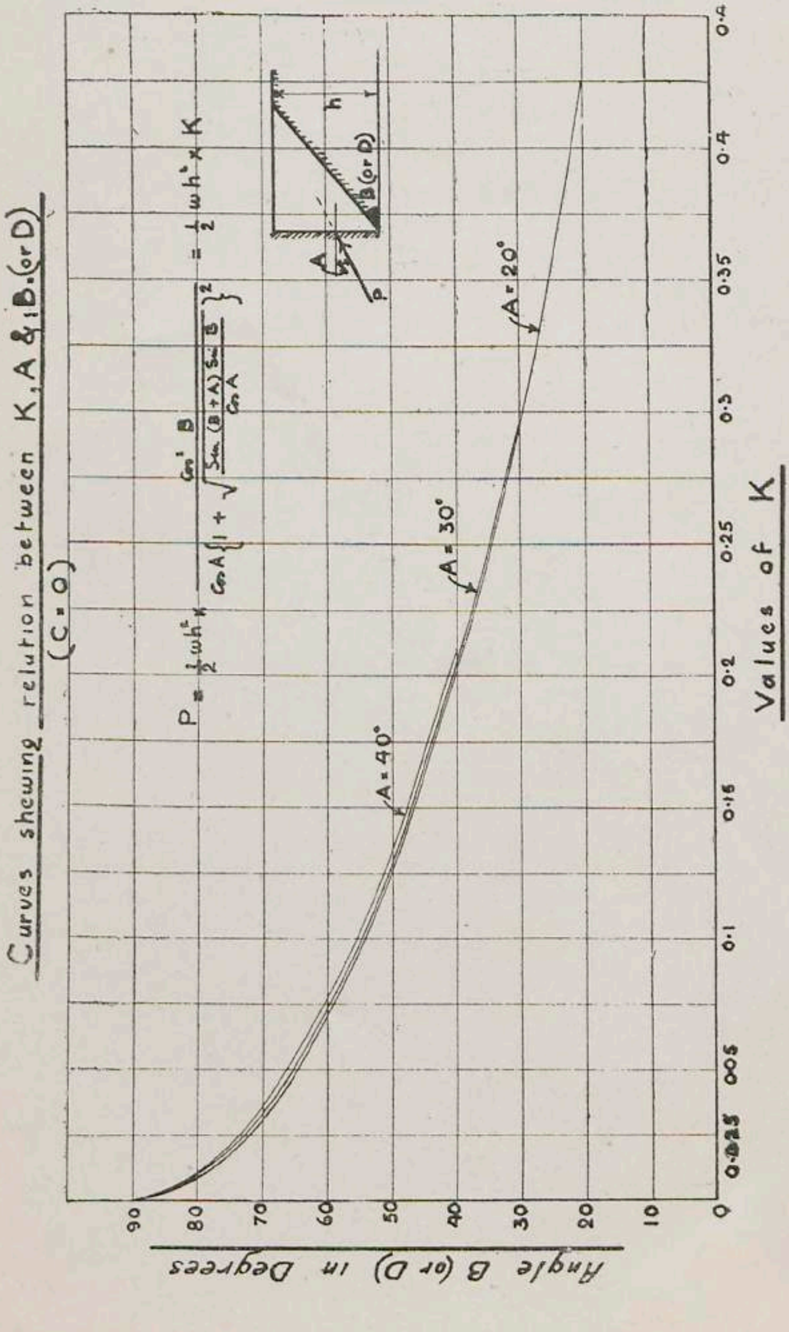


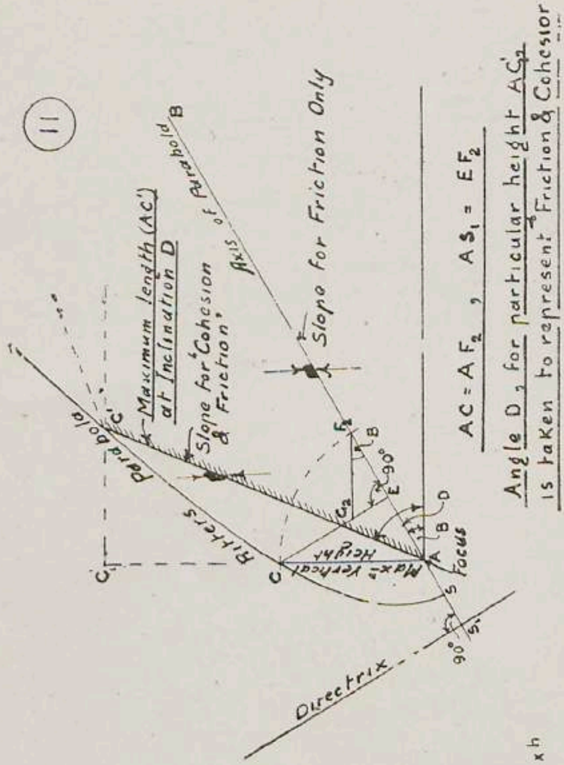
Rankine's Result:- P is parallel to upper surface

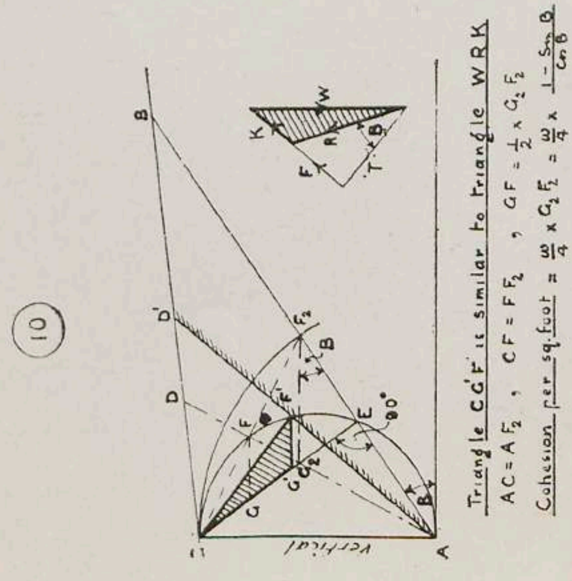

Corrected "Ordinary Theory"
Friction at Back of Wall.
Upper Surface
Rupture plane
W-S
Thrust in Earth
Strut
Thrust in Wall
I & II Combined same as III
Triangles of Forces

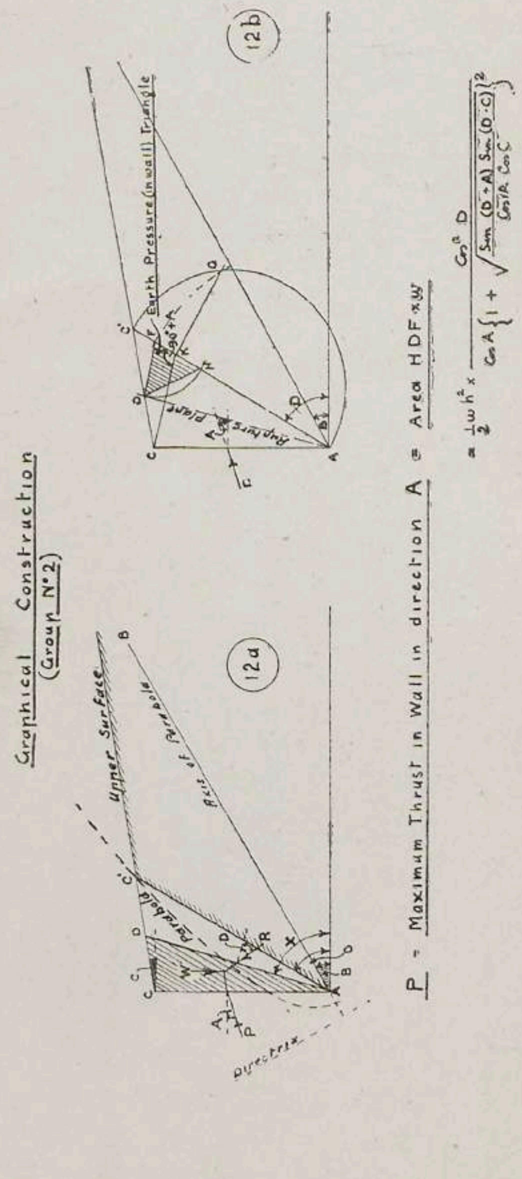


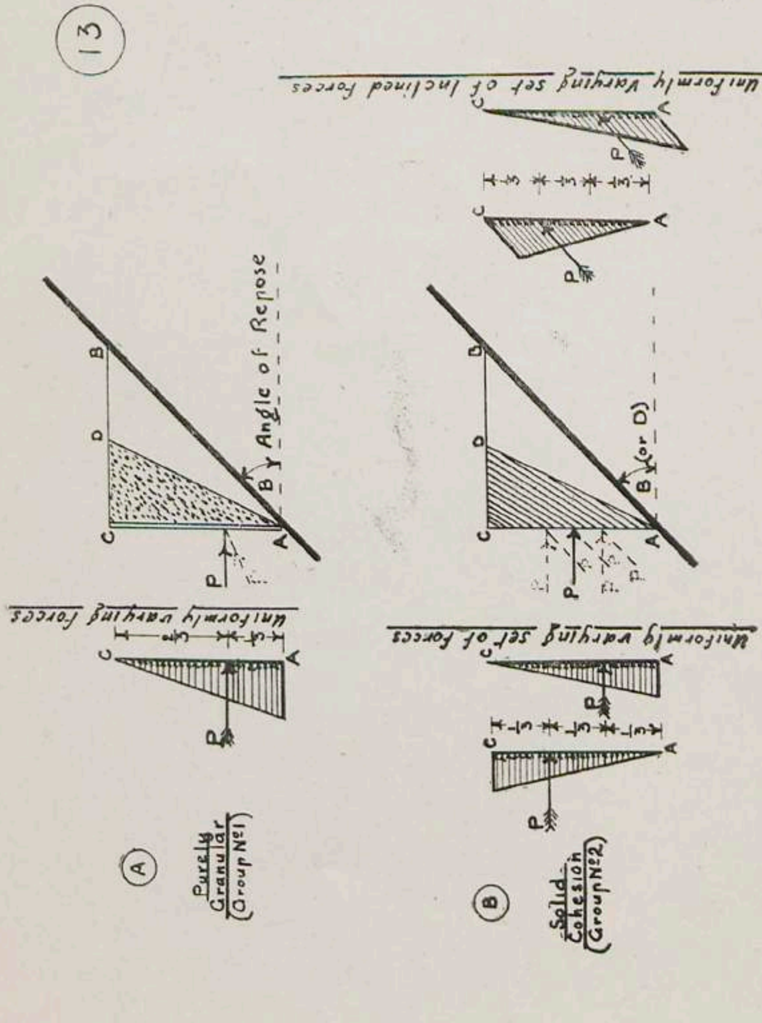
GROUP No. I.
Corrected Theory P=Area $H.D_1F$ x w (Shown in full line).
Old Theory P=Area $H_1D_1F_1$ x w (Shown in dotted line).

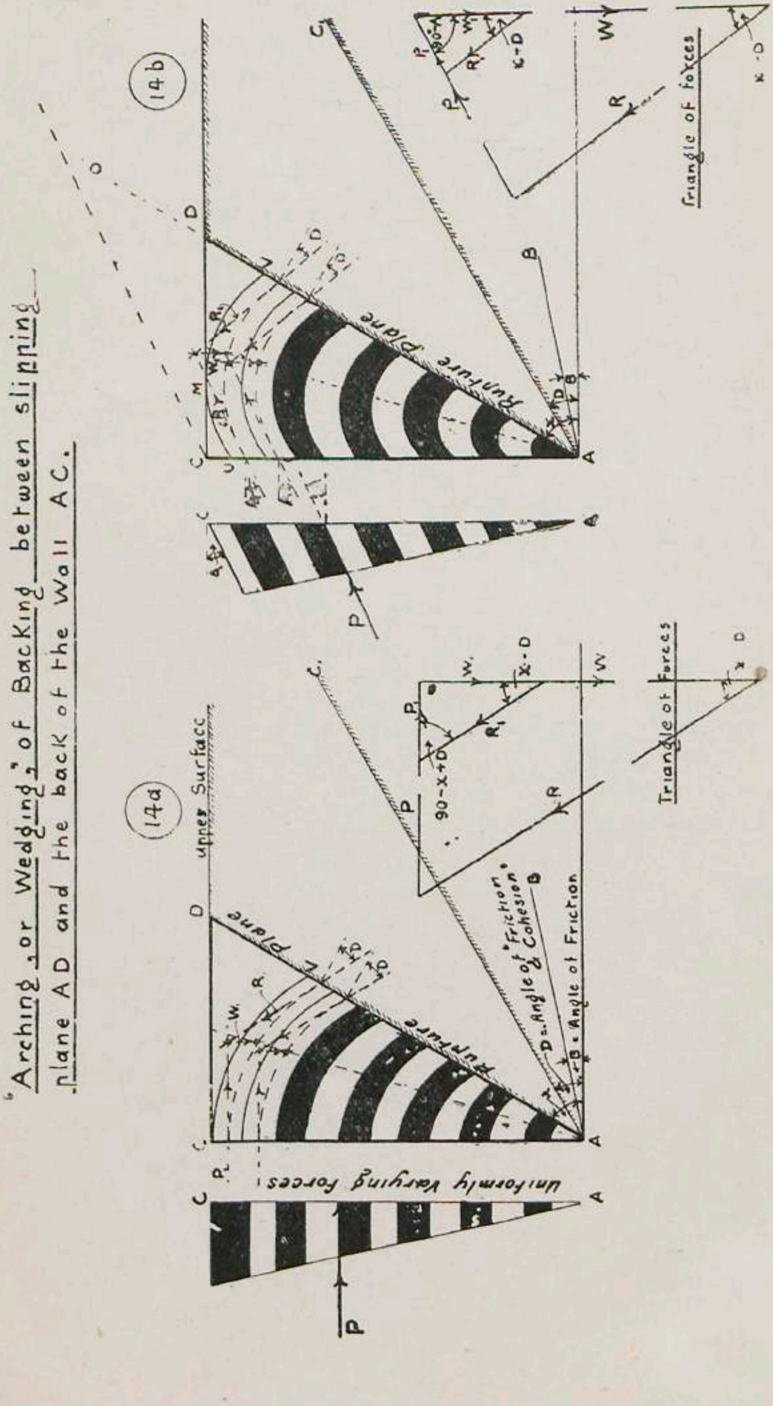

Curves shewing relation between K, A & B. (or D)
(C = O)
A = 40°
A = 30°
A = 20°
h
B (or D)
A
P
Values of K
Angle B (or D) in Degrees
0
0·025
0·05
0·1
0·15
0·2
0·25
0·3
0·35
0·4
0
10
20
30
40
50
60
70
80
90

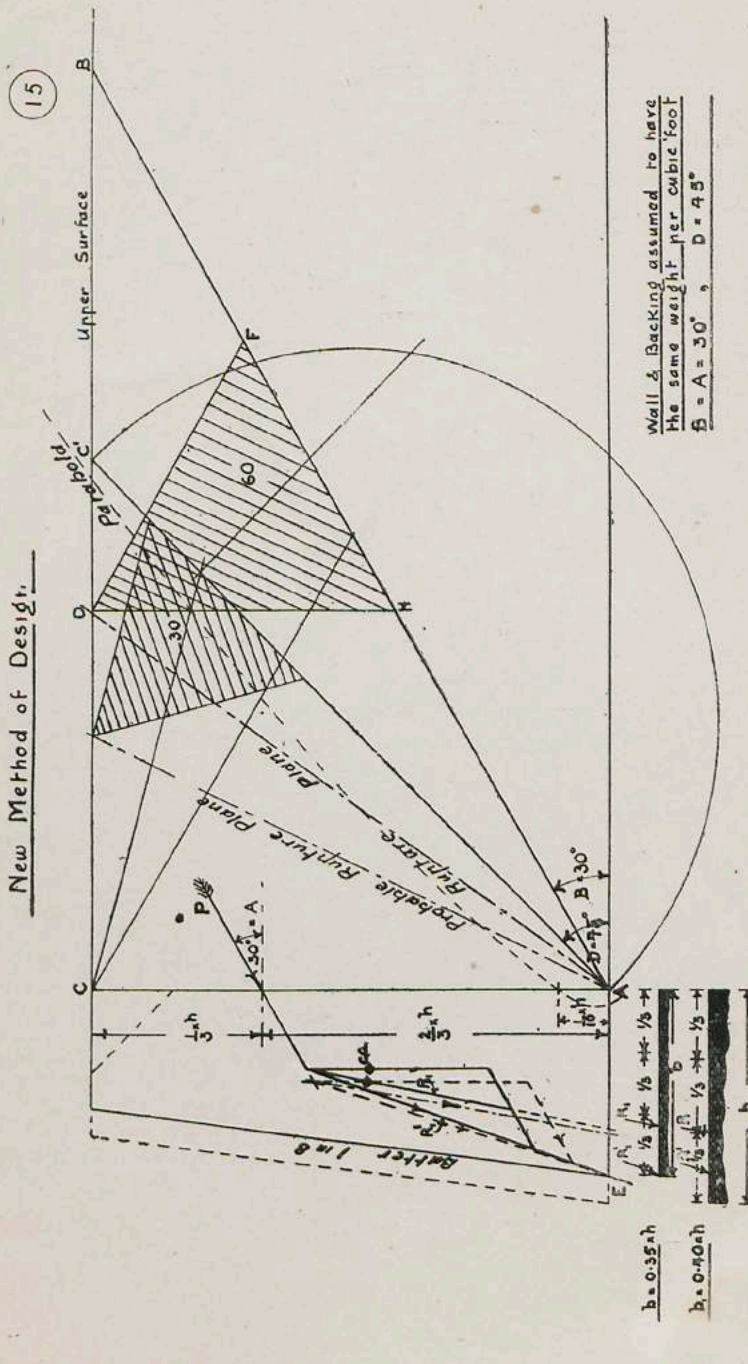

11
Maximum length (AC') at Inclination D
Slope for Cohesion & Friction
Axis of Parabola
Slope for Friction Only
Ritter's Parabola
Max.m Vertical Height
Focus
Directrix
AC = AF2 , AS1 = EF2
Angle D, for particular height AC'2 is taken to represent Friction & Cohesion

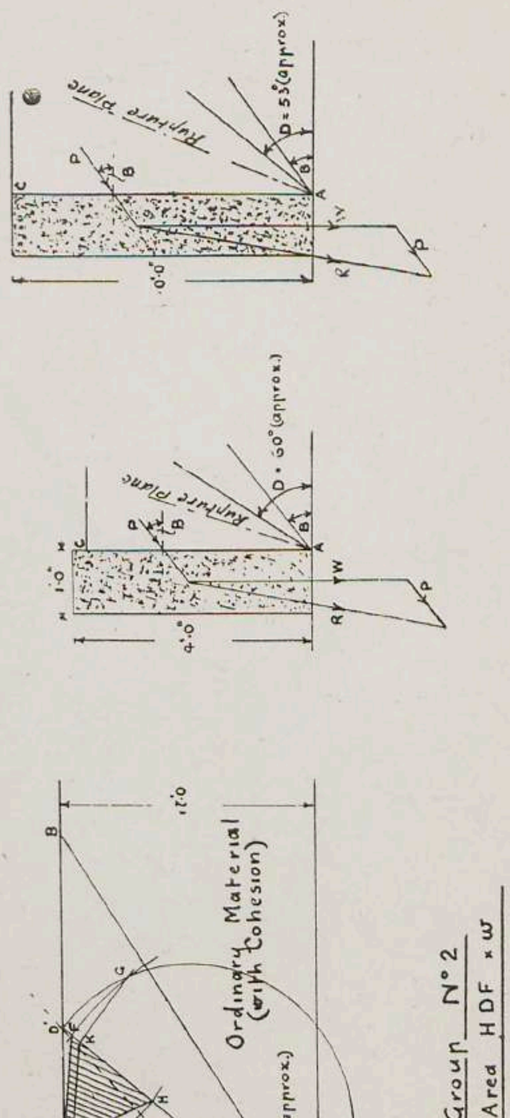

10
Vertical
Triangle CC'F' is similar to triangle WRK
AC = AF2 , CF = FF2 , GF = 1/2 x G2 F2
Cohesion per sq. foot = w/4 x G2 F2 = w/4 x (1 - Sin B)/(Cos B) x h


Graphical Construction
(Group N° 2)
12a
12b
Upper Surface
Axis of Parabola
Parabola
Directrix
Rupture Plane
Earth Pressure (in wall) Triangle
P = Maximum Thrust in Wall in direction A = Area HDF × w


13
A
Purely Granular
(Group No. 1)
Uniformly varying forces
Angle of Repose
B
Solid Cohesion
(Group No. 2)
Uniformly varying set of forces
B (or D)
Uniformly varying set of inclined forces

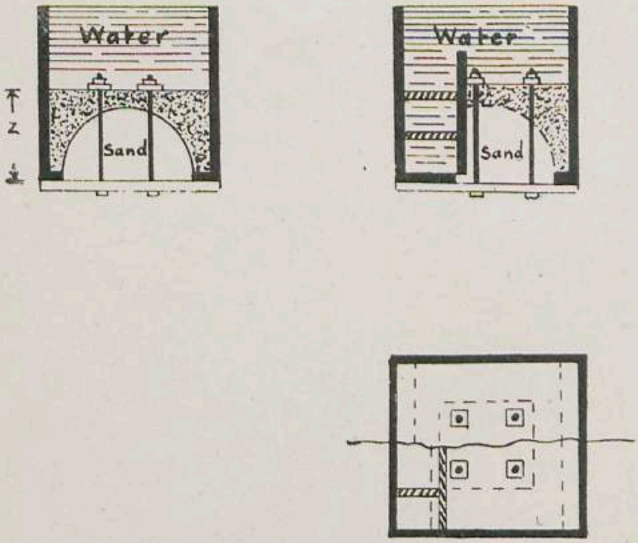

"Arching, or Wedging," of Backing between slipping plane AD and the back of the Wall AC.
14a
14b
upper Surface
Uniformly varying forces
Rupture plane
D = Angle of "Friction & Cohesion"
B = Angle of Friction
90-x+D
x-D
Triangle of Forces
Triangle of forces


15
New Method of Design
Upper Surface
Parabola
Probable Rupture Plane
Rupture Plane
Batter 1 in 8
B = 30°
60
30
Wall & Backing assumed to have
the same weight per cubic foot
B = A = 30° , D = 45°
b = 0·35×h
b, = 0·40×h


16a
Burgoyne's
16b
Baker's
16c
Hone's
Ordinary Material
(with Cohesion)
Rupture - Plane
Parabola
D = 51°(approx.)
D = 60°(approx.)
D = 55°(approx.)
Rupture Plane
Group N° 2
P = Area HDF × w

Meem's Experiment

(17)



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